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THREAT EXPERT SYSTEM TECHNOLOGY ADVISOR

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APPENDICES

- A Interview with Grady Wilson, NASA test pilot on April 6, 1987.
- B Interview with four helicopter pilots at the Marine Corps Air Station (MCAS), Tustin, CA on May 5, 1987.
- C SBIR Phase I Solicitation: "Threat Expert System Technology Advisor."

PROJECT SUMMARY

The purpose of the Phase I research, "Threat Expert System Technology Advisor", was to develop a prototype expert system to determine the feasibility of using expert system technology to enhance the performance and survivability of helicopter pilots in a combat threat environment while flying NOE (Nap-of-the-Earth) missions.

The basis for the concept is the potential of using an Expert System Advisor to reduce the extreme overloading of the pilot who flies NOE missions below treetop level at approximately 40 knots while performing these functions:

- o Monitoring all Avionic and Weapon systems.
- o Situation awareness of all aspects of the tactical situation.
- o Assessing the threats reliably.
- o Making split-second flight decisions
- o Making split-second weapon deployment decisions.

Our ultimate goal is to develop a Threat Expert System Advisor which provides threat information and advice that are better than even a highly experienced copilot.

The research for Phase I consisted of the following tasks:

- o Defining NOE Threat Scenarios where meaningful rules can be established.
- o Defining the terrain environment for the NOE Threat Scenario.
- o Interviewing helicopter pilots who have experience flying NOE missions.
- o Reviewing the TAC manuals.
- o Developing the rules and heuristics used by the pilots in threat situations and obstacle avoidance.
- o Designing and implementing the Threat Expert System and its interfaces to other modular experts.
- o Designing and implementing the user interface graphics with the Threat Expert System including the graphics display, text messages and voice response.
- o Developing the prototype Threat Expert System Advisor for a feasibility demonstration.

The results clearly show that the NOE pilot needs all the help in decision aiding and threat situation awareness that he can get. It clearly shows that heuristics are important and that an expert system for combat NOE helicopter missions can be of significant help to the pilot in complex threat situations and in making decisions.

We conclude from the pilot interview, tactics and prototype expert system that a more extensive version interfaced to flight simulators needs to be developed and tested. This real-time system with a pilot interface in the simulation facility is a next necessary development step for eventual integration into the helicopter for flight test demonstration.

FINAL REPORT
THREAT EXPERT SYSTEM
PHASE I

1.0 INTRODUCTION

Helicopter roles and missions have changed dramatically in the last few years. Having proven themselves with the successes of the assault and gunship roles during the Vietnam era the tactics and missions definitions have been extended and revised, relying on the helicopter to play an ever-increasing role in scout and attack missions as well as the more traditional rescue and supply missions. All of these missions require penetration well beyond the FEBA into or through areas which are defended by a proliferation and a variety of lethal and highly mobile threats. Nap-of-the-Earth (NOE) flight is a tactic which has been developed as an effective counter to these active threats, but this tactic significantly increases the helicopter vulnerability to passive threats, both natural (eg. rocks and trees) and man-made (wires, towers/poles, bridges and structures). NOE flight also increases the pilot's stress and workload, makes manual navigation very difficult and requires extensive training and practice to maintain pilot proficiency. To exploit the potential of the helicopter's versatility and the advantages of NOE flight, innovative techniques must be applied to the helicopter navigation and threat detection, assessment and avoidance/negation to provide rapid, highly reliable and easily understood information and advisories or commands to the pilot. The approach considered in this study is the application of Artificial Intelligence (AI) techniques, the expert system approach in particular, to the threat assessment and response functions. This report discusses the expected application of these AI techniques in the operational system and describes the

efforts and accomplishments of the Phase I study portion of the system development.

2.0 BACKGROUND

The typical NOE mission, whether it be scout, attack, rescue or supply, will be preceded by a route planning session which takes into account known and probable threat locations, detailed terrain and foliage data and friendly and hostile troop concentrations. Both primary and alternate routes to the destination(s) (including route branches at appropriate decision points) will be defined with navigation check points. The planned routes will be chosen to take advantage of masking capability to minimize exposure to actual or potential threats, both active and passive.

During the actual mission, the pilot will proceed to the objective according to the pre-mission plan, adjusting his flight details (speed, altitude and masking) according to perceived conditions. Accurate navigation is required to assure conformance with the route plans; frequent stops (periods of hovering) for checking against maps may be required if precise onboard navigation equipment is not available. The crew must continually be on the alert for unexpected threats and obstacles and the pilot must be prepared to quickly adjust his flight parameters or even his route based on changing threat conditions. Similar conditions and techniques apply during travel to any successive target or operational areas and during the trip back to friendly territory.

The success of the mission in terms of both survivability and the effective prosecution of the mission objectives (i.e. the destruction of targets, the surveillance of a target area, rescue of friendly personnel or the delivery of troops or supplies) depends on the ability to sense and locate threats or potential

threats, correctly assess the situation and rapidly make and implement decisions which will minimize the danger from the threats without significant compromise of the mission.

There are then three important aspects to the success of the mission other than piloting skills; 1) route planning , 2) accurate navigation and 3) continual threat assessment and timely response to any changes in the threat situation. The success of threat assessment/avoidance is related to both the route planning/replanning and navigation capability. However, the development of automated route planning capability and of accurate navigation equipment is the subject of ongoing parallel efforts. The automation of the threat assessment and improvement of the efficiency of the pilot's threat evaluation and decision making capability are the primary subjects of this study. The discussion of the threat assessment/response problem and of the development of a Threat Expert System solution to the problem is presented in 2.1 through 2.3 below.

2.1 Threat Assessment Problem/Requirements

Three types of threats must be addressed in the threat assessment task: active threats (weapons), passive threats (obstacles) and adverse environmental conditions. The primary active threats which must be avoided or negated are:

- o Air defense guns
- o Man portable/launched missiles
- o SAM Systems
- o Aircraft (rotary - or fixed-wing)
- o ESM and EO countermeasures

The primary response to these threats is avoidance; i.e. evasion, if their existence/location can be ascertained in time, or escape when the threat is encountered unexpectedly. The primary

avoidance technique is to use routes which circumvent the threat envelope and to exploit terrain and foliage masking to prevent detection or attack by known or potential threats when the threat envelope must be approached or penetrated.

The passive threats are natural obstacles (trees and terrain features) and man-made obstacles (wire, towers, building, bridges) which must be avoided during NOE flight. The alteration of the flight profile for obstacle avoidance - speed change and/or direction and severity of maneuver - must be defined with consideration of the current active threat situation to minimize any additional exposure to hostile weapons.

Sensors which may or could be available on the aircraft for threat detection/evaluation (in addition to visual detection by the crew) are:

- o Low-light-level or All-light-level T.V.
- o FLIR
- o Laser Rangefinder associated with an EO sensor
- o ESM for threat detection/warning as well as passive target location

A precise on-board navigation system is an important adjunct sensor for threat assessment and threat sensor data processing. Onboard radar is possible but not likely because the cost/sophistication of a radar which would provide acceptable operation in the NOE environment may be prohibitive and use of such an active sensor could be dangerous because of the potential of alerting the active threats.

The air defense guns, SAMs and countermeasures are detectable by both EO and the ESM sensors. Enemy aircraft can be sensed by EO sensors but will likely not be emitting electromagnetic energy. Man-launched missiles are difficult to detect by any means, but

the IR & TV sensors may be able to detect the launch plume. Wires are the most serious passive threat because they are virtually impossible to see or counter. Currently, sensors which can detect wires and provide a timely alert are not available, but such sensors are being very seriously investigated with some encouraging results.

A significant data base is required for a threat assessment/avoidance system. A large volume of pre-mission data must be loaded immediately prior to flight. The latest threat data, from intelligence or other sources, for the area of operation must be provided. This threat data base includes type and location of each known threat, the time of the data validity (last sighting, for example), the characteristics of each type of threat and an indication of the confidence in each data entry. Detailed, high-resolution terrain data along the planned and alternate routes and for the area of operation (target or destination area) must be provided. Finally, the definition of the planned and alternate routes must be stored in terms of way points, check points, branch points, etc. During flight, updated threat information from a C³I data link may be received and manual input data from the pilot/crew must be accommodated. These real-time inputs must be quickly integrated into the threat data base.

During flight, the current position of the aircraft relative to the known threats must be continually monitored with assessment of the effective masking by the intervening terrain in order to evaluate the threat situation. If conditions of excessive exposure are found to exist, an unexpected immediate threat is encountered and/or an alert is received from a sensor, immediate reassessment of the threat situation must be made and any required evasive action quickly determined and implemented.

An Expert System implementation of a threat assessment system which combines and processes all available data (data base and

in-flight inputs), assesses the threat situation and informs and advises the pilot, can potentially relieve the pilot of most of the threat-related workload and enhance the chances of mission success. However, if such a system is to be effective it must have the following characteristics:

- o High Reliability
- o Quick Response
- o Efficient Pilot Display/Interface
- o Supportable Implementation

High reliability implies both accurate threat assessment and low false alarm rate as well as low equipment failure rate. In particular, under battlefield conditions such a system should provide assessments/decisions comparable to those which would be made by an expert pilot under ideal, non-stressing conditions. Quick response implies real-time processing and immediate integration of new data and resulting reassessment of the threat situation. To be useful to the pilot (and therefore to be accepted by him) the assessment information must be condensed, clearly presented, easily assimilated and unambiguous so that there will be no delay or confusion in the pilot's understanding. Provisions must be made to supply more detailed or back-up information when and if the pilot wants it. The controls/displays must provide an interactive interface for ease of command, data request and data entry by the pilot or crew. Finally, to be supportable the system must be capable of implementation in flyable hardware (use a flight size/weight processor). Its software must be fully validated and readily maintainable; i.e., easily updated with new algorithms/rules to accommodate new or evolving threats and tactics. The system must also include an efficient and reliable preflight data preparation and loading capability to accommodate the large threat, route and terrain data bases that must be loaded into the onboard processor memory immediately prior to take-off. All of these requirements

and considerations must be included in the Threat Expert System planning and development.

2.2 Operational Threat Expert System

A potential long-term (operational) solution to the problem briefly described in the above paragraphs is the development of a Threat Expert System to assist the pilots in the immediate evaluation of the existing and rapidly changing threat conditions, provide alerts as and when appropriate and advise them regarding precautionary or evasive actions which are consistent with the mission objectives and the aircraft performance capabilities under existing load and environmental conditions. The overall goals of such a system would be to simultaneously enhance the survivability of the aircraft in whatever threat environment exists and to increase mission effectiveness. A corollary objective is to decrease the pilot's workload by relieving him of the threat assessment and evaluation task, thereby allowing him to concentrate on the tactical situation. In this system configuration the pilot is relieved of the task of continually monitoring and correlating the data from the threat sensors and the pre-mission intelligence data base. His task is then (in addition to controlling the aircraft) primarily that of decision-making using the summary threat evaluation and advisory data provided him via highly efficient displays and other communication media and causing these decisions to be implemented using simple controls which interface with the Threat Expert System.

The implementation of this operational threat expert system is comprised of three major elements: 1) a powerful on-board processor (including storage for the pre-mission and updated threat and environmental data bases) which processes the threat data and applies the expert system rules and decision making algorithms, 2) an efficient communication/control interface with

the pilot and 3) real-time data/control interfaces with the threat sensors and helicopter's avionics.

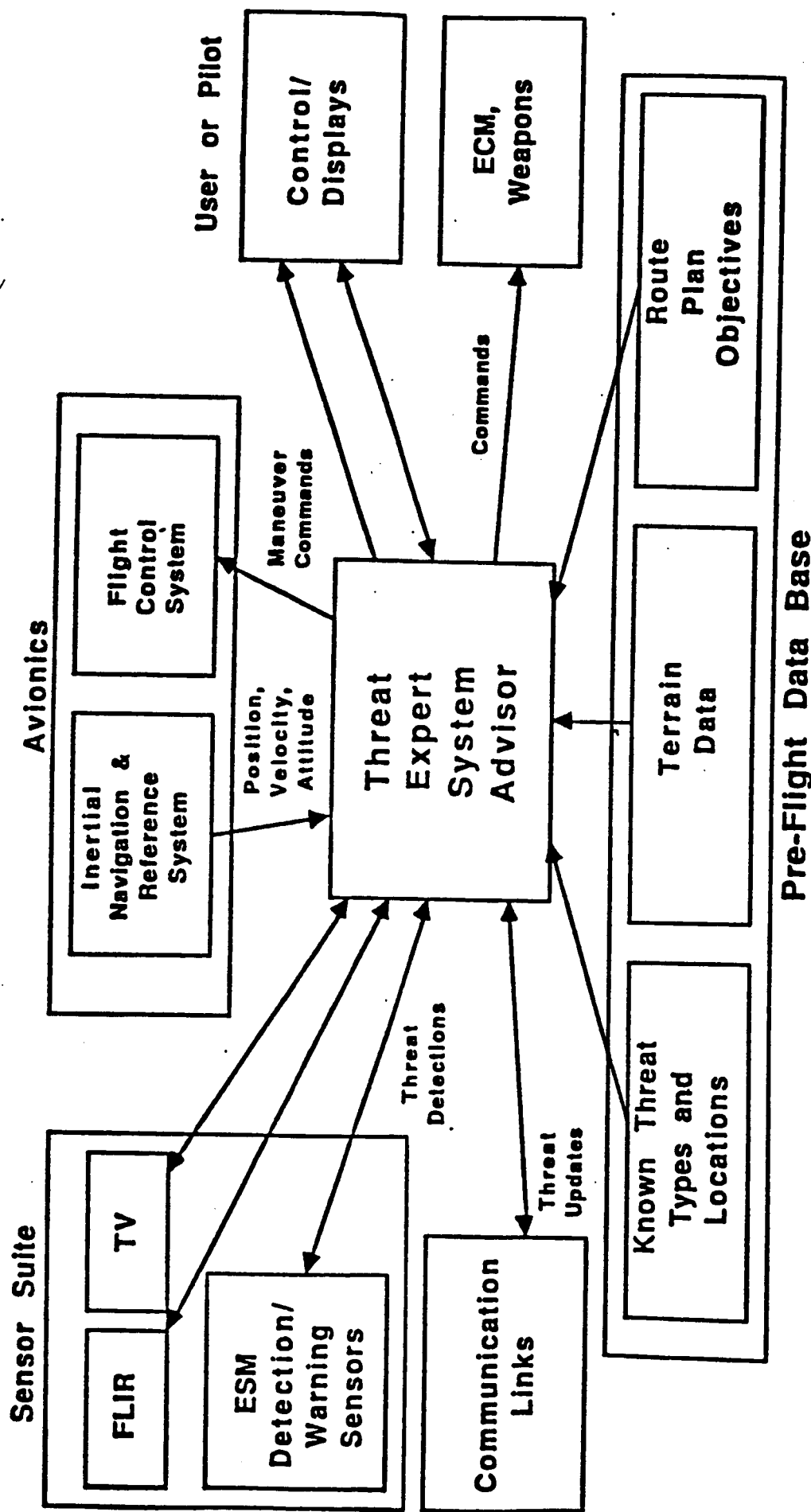
"Efficient" communications implies the presentation of the threat situation, decision and advisory data to the pilot quickly and in a form which he can readily assimilate, correctly interpret and evaluate and provision of the capability to rapidly implement decisions which he makes. This control/display capability is a very important aspect of the threat expert system implementation and will require significant parallel effort for its development. The interface to the avionics quite likely will include provision for commands to the autopilot, sensors and weapon control subsystems which the Threat Expert System will generate to implement the pilot's decisions.

A functional block diagram of the operational program is presented in Figure 1. The Threat Expert System is depicted in terms of the functional interfaces of the system and its major functional elements; the Pre-flight Data Base and the Threat Expert System Advisor. Threat detections from the sensors and any threat update information from the C³I links will be used to update the threat data base. Critical alerts from the threat sensors will be provided to the pilot immediately and included in the Threat Expert System Advisor processing. As changes in threat and tactical situation are perceived, the program will reassess the situation and provide advisories to the pilot, when appropriate. These advisories will include the selection of alternate routes included in the Route Plans portion of the pre-mission data base.

2.3 Expert System Development Process

Figure 2 indicates the anticipated major steps in the development of the required Threat Expert System. The first step is the Phase I study which is the subject of this report. Three

Expert System Functions and Interfaces



EXPERT SYSTEM FUNCTIONS AND INTERFACES

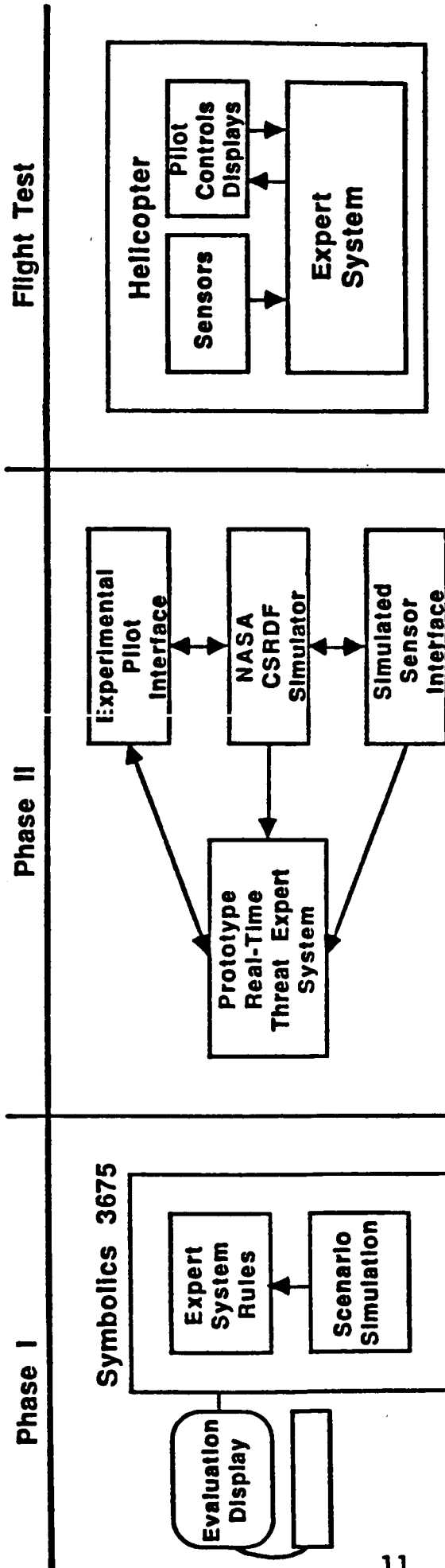
FIGURE 1

subsequent major development phases have been defined as indicated in Figure 2.

The goal of this Phase I study was to establish the feasibility of the threat expert system. The approach was to define a representative mission scenario and a spectrum of threats, then to develop and evaluate a limited set of rules using the defined scenario and a variety of threat combinations. The rules and scenario simulation are implemented in a Symbolics 3675. An important adjunct, which was developed during the Phase I study, is an evaluation display which depicts the threat situation, shows the progress through the scenario and indicates results of the application of the Expert System Rules. This system and the results of the Phase I study are discussed in sections 3, 4, and 5 of this report. A brief discussion of Phase II is included in section 6.

The development effort during the Phase II laboratory/simulation phase must include two major thrusts: 1) the expansion and refinement of the rule base to deep knowledge which can accommodate and provide appropriate responses to the wide spectra of potential mission scenarios, aircraft statuses and threat conditions and 2) the continuing development of the requirements and specifications for the pilot interface equipment (displays, controls, aural and other non-visual communication media) including their data content, formats and update/sample rates. Other aspects of this study will be the definition of the threat sensor requirements and their expected capabilities during the flight test and IOC time-frames as well as the compilation of an extensive up-to-date threat data base. The threat data base will include the detailed characteristics and performance capabilities of all active threats; the proliferation potential and doctrines/tactics for deploying and using these weapons; and the characteristics and milieus of all types of passive threats. The threat data base will be an ongoing "live" entity, continually

Expert System Development Sequence



Goals:

- Establish Feasibility of Expert System
- Develop & Evaluate Extensive Set of Rules (Deep Knowledge)
- Establish Pilot/Sensor Interface Requirements
- Prove & Optimize the Expert System in a Real-Time Environment
- Prove the Expert System in Realistic Flight Scenarios

EXPERT SYSTEM DEVELOPMENT SEQUENCE

FIGURE 2

updated to reflect changes in the threat characteristics and populations during the flight test and operational life of the program.

The final phase of the Threat Expert System development will be the flight testing of a "brassboard" prototype system in a representative helicopter for the purpose of proving the Expert System in actual flight conditions and realistic scenarios. The "brassboard" system will include a prototype pilot interface and representative state-of-the art threat sensors installed in the helicopter. The expert system may be implemented with a prototype processor mounted in the aircraft or a ground based processor interfacing the airborne sensors and controls/displays via a high-speed, two-way data link.

Throughout the Phase II and Laboratory Development/testing phases implementation considerations must be continuously emphasized to assure feasibility of incorporating the Threat Expert System into operational helicopters with flexibility for quick revision of data and rule bases in response to new and evolving threats and doctrines.

3.0 TECHNICAL OBJECTIVES OF THE PHASE I STUDY

3.1 Summary of the Phase I Objectives

The main purpose of this research was to achieve the following four objectives:

- o Establish the feasibility of using expert system technology to respond to pilots needs in making decisions to handle threats during combat while flying NOE helicopter missions.

- o Develop a knowledge base using the knowledge of expert pilots with NOE helicopter combat experience.
- o Provide threat assessment and correct response to obstacles and threats for NOE scenarios.
- o Advise the pilots on the appropriate course of action in handling threats and obstacles.

3.2 Relationship of Objectives to the Work Performed

The first of our objectives was achieved by developing and demonstrating a prototype expert system for handling threats and advising the pilot in making decisions during threat situations. The Threat Expert System handles both air defense guns and surface-to-air missiles. The threats may be known or unknown and are placed anywhere in the geographic area defined by the mission scenario on the graphics interactive display.

Our second objective was achieved by the interviews we conducted with experienced helicopter pilots who flew NOE combat missions in Vietnam. These pilot interviews were recorded on tape, transcribed into text and are included in the appendix.

A detailed description and results of the pilot interviews are included in section 4.2.

The pilots described their decision-making process in handling various threat situations for the selected mission scenario. The threat assessment and obstacle avoidance methods used in the expert system were based on the information given by these experienced pilots during the interviews. From this information the rule base was generated.

The messages to the pilot which are generated by the expert system during specific critical decision points are the advice given. It is assumed for Phase I that the helicopter pilot accepts the advice and proceeds.

The Threat Expert System software was delivered to NASA Ames as well as instructions to run the expert system. The AI laboratory at NASA Ames will run the demonstration of the expert system.

3.3 Some Important Assumptions and Constraints

The necessary assumptions and constraints made during the performance of this research were as follows:

Assumptions:

- o The threats used in this system were limited to Air Defense guns and surface-to-air missiles. In Phase II the complete threat situation will be included which is shown in Figure 3.
- o The obstacles shown in the graphics display of the NOE threat scenario were limited to trees, bridges and wires.
- o The user interface assumes the user to be an evaluator of the system and consequently gives an overview of the system.

Constraints:

- o The graphics display obviously is not three-dimensional and therefore certain assumptions for the threat envelope and flight path were made.

Threat Summary

Active (Attack Avoidance/ Negation)

- Air Defense Guns
- Shoulder-Launched Missiles
- SAM Systems
- Aircraft (Rotary-Wing, Fixed Wing)
- EM & EO Countermeasures

Passive (Obstacle Avoidance)

- Manmade Obstacles (Towers, Buildings, etc)
- Natural Obstacles (Trees, Terrain)

Environmental

- Adverse Weather/ Poor Visibility

Visual	E-O	EM
X	X	X
X	X	
X	X	X
X	X	
	X	X
X	X	
X	X	
	X	
	X	
	X	

- o Time and effort limited the development to one NOE mission design with one alternate route.

4.0 PHASE I TASKS

The work performed for the Phase I contract is described in the following sections. This includes a description of the technical approach for achieving the Phase I objectives and a summary of the tasks performed. The techniques and resources used to perform the tasks are also described here.

4.1 Phase I Technical Approach

The approach taken to develop a prototype Threat Expert System advisor for Phase I consisted of the following:

- o Knowledge acquisition which included the problem discussion, analysis and data gathering achieved by the pilot interviews which are discussed later in the report.
- o Knowledge-base development which included the extraction of information from the pilot interviews, manuals, etc., and encoding of this information into the knowledge base of the expert system.
- o Definition of the Expert System architecture and system requirements.
- o Design and development of the Threat Expert System Advisor.

4.1.1 Summary of the Phase I Tasks Performed

The work performed under the Phase I contract included the analysis, design and development of a prototype Threat Expert System Advisor which would run on the Symbolics 3675. The system was delivered to NASA Ames with a tape of the source code and detailed instructions for running the system.

The specific items which were performed under this research effort are as follows:

- o Definition of the threat scenario and NOE mission where meaningful rules were established. Helicopter pilots with NOE combat experience were interviewed and commented on the specific scenarios.
- o Definition and development of the threat data sources and their use in decision-aiding for both known and unknown threats. A complete threat and obstacle summary is described in Figure 3. Only air defense guns and surface-to-air missiles were considered in Phase I. Obstacles included in Phase I were trees, bridges and wires.
- o Development of the rule base and heuristics used by the pilots in threat situations and obstacle avoidance techniques.
- o Definition and design of the Threat Expert System architecture and interfaces.
- o Design and development of the Threat Expert System software which includes several other "Expert" modules necessary for the operation of the Threat Expert

System. This is described in detail later in this section.

- o Design and development of the user interface with the expert system which includes a detailed graphics display representing the NOE Mission terrain, the pilot interface, the text messages, voice synthesizer response and the explanation facility.

4.1.2 Techniques and Facilities Used

The software design and development was performed by the Odetics knowledge engineer using the Automated Reasoning Tool, ART, by Inference Corporation. The Threat Expert System runs on the Symbolics 3675. Instructions for using the system are included later in this report. Each "expert" in the Threat Expert System was designed and developed in a modular fashion to interface with each other. The structure of the system was developed so that the Phase II development could enhance and build on this modular system.

4.2 Knowledge Base

A major part of the development of any expert system is the acquisition of the knowledge and information that is to be encoded in the expert system rules. In the development of the Odetics Threat Expert System, we identified four major sources of knowledge and information. They are: pilot interviews, helicopter tactical manuals, a video tape of a Fort Rucker NOE training flight, and time in a CH53 helicopter simulator. Each of these sources provided new as well as supporting information that could be used to build the rule base. Personal experience and heuristics were a major part of the knowledge gained from the pilot interviews and from the time in the simulator. While the

more codified and recommended doctrine on helicopter tactics was gained from the helicopter tactical manuals.

4.2.1 Pilot Interviews

The pilots we interviewed were: Grady Wilson, Former NASA Experimental Test Pilot; and Captains Mark Boyce, Brian Delahaut, Dave Kitsch, and Chuck O'Neal from the Marine Corps Air Station in Tustin, California.

We conducted three separate interviews with the helicopter pilots to try and get an experienced account of how to fly NOE and low-level helicopter missions. The interviews totaled about ten hours in length. All of the interviews were tape recorded, and two of them were transcribed for later review and analysis (see Appendix A and B. The interviews covered three topics of interest to this program. These topics are: the experience of the pilots, general information on NOE and low-level flight, and specific information on our scenario.

All of the pilots had a minimum of 1600 hours of flight time, with Grady Wilson having the most experience. In addition, Mr. Wilson has combat experience in Vietnam. The Marines are restricted from flying NOE missions on training flights because of the hazards involved. Instead, they limit their training flights to stay above 50 feet. Most of the experience the Marine pilots have is with larger assault support helicopters, as opposed to anti-armor or scouting helicopters.

When it came time to discuss our specific scenario, we formulated the questions so that their answers could be more easily encoded into rules using the ART syntax. We later found that this is generally not possible because of a different level of abstraction between what the pilots can vocalize and what can be expressed in ART. A major part of the knowledge acquisition task

became reducing the abstract answers given by the pilots into a set of rules that captured the essence of their answers.

4.2.2 Helicopter Tactical Manuals

Odetics was able to borrow two helicopter tactical manuals from the Marine Corps pilots. The manuals are: AH-1 Tactical Manual, Naval Warfare Publications 55-3-AH1, June 1986; and Assault Support Helicopter Tactical Manual, Naval Warfare Publications 55-9-ASH, November 1985. The information in these manuals is a very important part of the doctrine governing helicopter flight in the Marines. The pilots are regularly tested on all aspects of the information in the manuals. Successful completion of these tests is necessary to maintain their flight ready status. These manuals became an important source of information in many areas, particularly, weapon systems, mission planning and coordination, enemy threats, and day and night tactical flying.

Since we wanted to incorporate a radar warning receiver into our expert system software, the manuals provided valuable information on the use and features of the radar warning receiver used on these helicopters. Information on mission planning helped us select the Primary and Alternate Routes used in our demonstration. Characteristics of enemy threats aided in our selection of two prototypical threats, namely, the mobile air defense gun, and the fixed anti-aircraft missile site. Sections of the manuals dealing with day and night tactical flying helped to formulate our terrain following and obstacle avoidance rules.

4.2.3 Video Tape of Fort Rucker NOE Training Flight

NASA Ames Research Center provided Odetics with a copy of a video tape made during a NOE training flight at Fort Rucker, Alabama. Fort Rucker is the Army's training center for NOE helicopter flight, so a video tape of a training mission is a dramatic

visual presentation of what the pilot must cope with during an NOE mission. While there were no threats to avoid during the training flight, there were obstacles all along the route. Seeing the obstacles and the maneuvers used to avoid them much as the pilot who flew the mission did, added to our personal knowledge of NOE helicopter flight. This personal knowledge about helicopter flight permits us to correctly interpret the answers given during the pilot interviews.

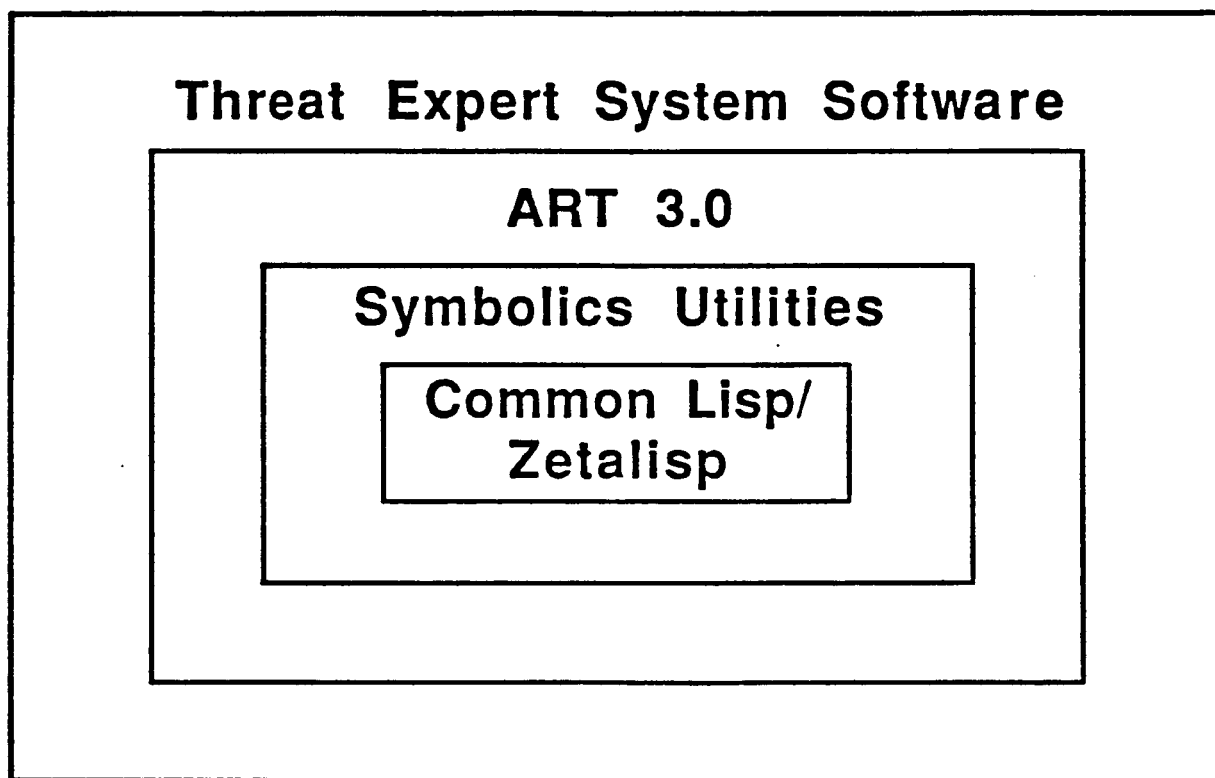
4.2.4 CH53 Helicopter Simulator

Since none of the Odetics personnel working on this project is an experienced helicopter pilot, we had no basis to fully understand the abstract concepts about pilot workload. This was, somewhat, alleviated by the opportunity to use a CH53 helicopter simulator located at the Marine Corps Air Station in Tustin, California. Lloyd Tripp, one of the Odetics knowledge engineers, was able to spend one hour at the controls of the simulated helicopter with Captain Mark Boyce acting as copilot. This was a good way to experience, first hand, the workload of a helicopter pilot and to gain a deeper understanding of the requirements for automated pilot aids.

4.3 Expert System Development

4.3.1 Threat Expert System Architecture

The Threat Expert System is built on top of several layers of software. This is illustrated in Figure 4. In the center, are Common Lisp and Zetalisp dialects of the LISP programming language. On a LISP machine like the Symbolics, LISP forms the kernel upon which all other layers of software are built. In this case, Symbolics adds a layer of utilities that includes all the functions of the operating system. It does not include such application programs as editors, LISP Listeners, and debuggers,



THREAT EXPERT SYSTEM SOFTWARE

FIGURE 4

but does include memory and window management functions among many others. Inference Corporation adds the ART 3.0 expert system shell layer. The outermost layer is the Odetics Threat Expert System. Because it is the outermost layer, the Threat Expert System can utilize not only the ART shell, but the Symbolics utilities and LISP language as well. The Threat Expert System utilizes this feature extensively by supporting the ART rules with functions coded directly in LISP. Coding functions directly in LISP allows you to express more complex conditions and actions in the ART rules than would be possible using ART alone.

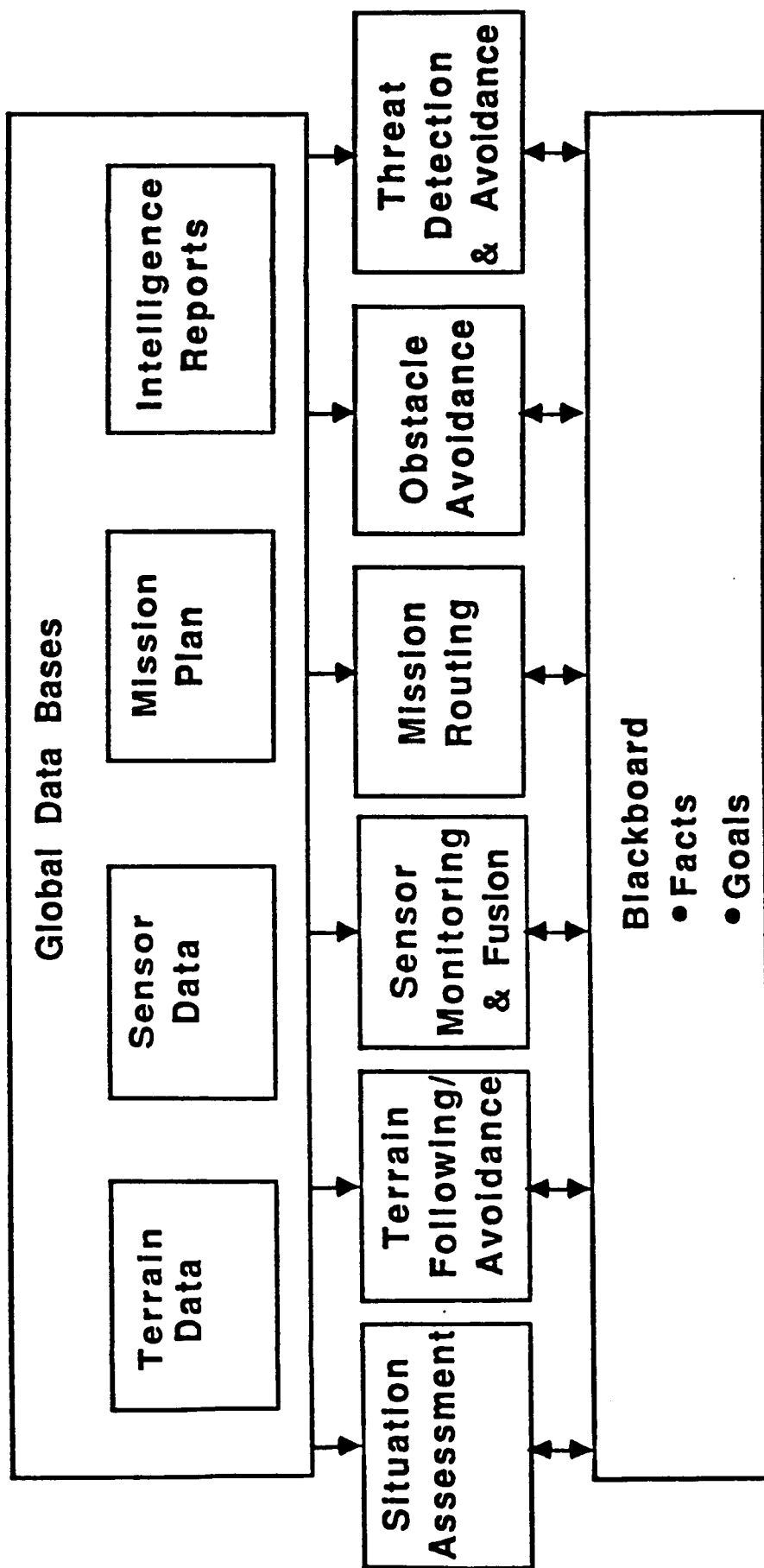
The architecture of the Threat Expert System is illustrated in Figure 5. It shows six experts reading data from four Global Data Bases and sharing information through a Blackboard. This type of architecture has the advantage of separating each of the experts as much as possible and thus simplifying their development and testing. Also, new experts can be added without major redesign or recoding of the existing expert system. This type of architecture also has the future growth potential of implementing each of the six experts on six separate processors for a much higher degree of parallelism than is possible with a single expert that does everything.

4.3.2 Phase I Prototype Threat Expert System Implementation

This section provides an overview of the implementation of the major blocks illustrated in Figure 5. Appendix C contains a more detailed explanation of the Threat Advisor implementation.

Global Data Bases

There are four Global Data Bases that are accessible to the six experts. They are: the Terrain Data, the Sensor Data, the Mission Plan, and the Intelligence Reports.



THREAT EXPERT SYSTEM ARCHITECTURE

FIGURE 5

The Terrain Data consists of 2300 data points spaced on a 10x10 pixel grid over the Primary and Alternate Routes. (See Figure 6 and Figure 7 for an illustration of these two routes.) Using a scale of five feet per image pixel, these data points are spaced about 50 feet apart. The data points contain information about the type of terrain in addition to its elevation. Knowing the type of terrain is important to the Terrain Following/ Terrain Avoidance expert. These data points are initially implemented as ART schemata (plural of schema) and later converted to a LISP array. This conversion is necessary from a practical point of implementation because of the great overhead associated with maintaining 2300 schemata. There is some loss of generality and ease of use because ART "understands" the schema structure but does not understand LISP arrays. This small loss of generality is more than made up for in implementation efficiency.

The Sensor Data comes from a simple model of a radar warning receiver and an obstacle detection sensor. The radar warning receiver detects the direction and signature of any emitting threats in the scenario based on a function of the helicopter's height, the distance to the threat, and a random number. The obstacle detection sensor detects the distance and direction to any obstacles within 250 feet of the helicopter. It was necessary to devise this obstacle detection sensor in order to get data to the Obstacle Avoidance expert.

The Mission Plan contains the location of the checkpoints for a Primary and Alternate Route. The number and location of the checkpoints was chosen based on the mission planning information in the Helicopter Tactical Manuals described in section 4.2.2.

The Intelligence Reports are interactively defined before the demonstration mission is started. (See section 4.3.3.3) The Intelligence Reports contain the type of threat, its location, and its threat boundary.

Situation Assessment

The Situation Assessment expert provides several different types of functions. It initializes the Blackboard to activate the other experts by writing the starting state of the helicopter. Once the other experts see this information on the Blackboard, they use it to determine the next state of the helicopter. Because the Terrain Following, Obstacle Avoidance, and Threat Avoidance experts all compute what they believe the next helicopter velocity should be, the Situation Assessment expert acts as an arbitrator and selects which one should dominate at that particular instant. (All velocities are calculated based on the helicopter having no mass.) It also provides an explanation facility so that an evaluator can query the system about its actions. In addition, most of the text and graphics that appears on the display is generated by the Situation Assessment expert.

Terrain Following/ Terrain Avoidance

The Terrain Following/ Terrain Avoidance expert has a set of rules derived from the pilot interviews. The rules try to strike a balance between safety and terrain masking much like a human pilot does. The rules examine the surrounding terrain and try to match the best flying technique that applies. The expert is primarily directed through goals set by the Mission Routing expert. The Terrain Following/ Terrain Avoidance expert does what it thinks is correct to achieve the next goal.

Sensor Monitoring and Fusion

The Sensor Monitoring and Fusion expert primarily tries to correlate data from the radar warning receiver with Intelligence Reports. If such a correlation is possible, it increases the probability that the radar warning receiver is picking up

emissions from a threat that really exists. If the number of consecutive radar warning reports exceeds three, then the direction is indicated on the radar warning receiver icon in the Information window. This is intended to eliminate the indication of weak signals.

Mission Routing

The Mission Routing expert selects between the Primary and Alternate Routes based on Sensor and Intelligence information. If a goal on the Primary Route is encompassed by a threat boundary, it will select the Alternate Route. If both routes are blocked, it will abort the mission and pause the demonstration. It also determines the flight path by reading the Mission Plan and establishing the next checkpoint as a goal to be achieved by the other experts.

Obstacle Avoidance

The Obstacle Avoidance expert consists of a set of rules encoded from the pilot interviews. There are three types of obstacles that the rules can handle; trees, bridges, and wires. When approaching a tree, the expert will try to first find a path around the tree before it pulls up to go over it. This is primarily to reduce exposure to threats. The small bridge in our scenario will be avoided by popping over it. Our pilots determined it would be better to risk the short exposure time of a pop up maneuver than slowing down near the bridge to go around it in a rudder turn. Wires will be avoided by popping over the nearest supporting pole.

Threat Detection and Avoidance

This expert tries to detect threats and steer the helicopter around their boundaries. For known threats, it can get the

location of the threat and its boundary from the Intelligence Reports database. For unknown threats, it uses the Sensor Data to try to estimate the position of an emitter using triangulation. Once a position estimate has been established, a default threat boundary will be determined based on the type of threat that is emitting. It will then try to avoid this estimated threat boundary.

Blackboard

The Blackboard is implemented as a record-like structure called an ART schema. This type of structure permits labeling of the information in the Blackboard which facilitates access by the experts that need the information. Because of a limitation in the ART system, the Blackboard is not isolated in its own area of memory. Instead, it is part of a global fact database that ART maintains. This limitation does not affect the function of the Blackboard.

4.3.3 Description of the Threat Expert System Demonstration

The knowledge contained in the rules and functions of the Threat Expert System is intended to be evaluated using an evaluation display devised at Odetics. The evaluation display was designed to show enough information so that an evaluator looking at the display could determine the current state of the helicopter as well as its history. From this information, the evaluator could then deduce whether there was sufficient knowledge or the "right" knowledge in the expert system to handle the current situation. The evaluation display consists of four windows. They are: the NOE Threat Scenario, the Control, the Information, and the Query Response windows. Each of these windows plays a distinct role in informing the evaluator about the knowledge in the system. Figure 6 is a picture taken of the evaluation display before the example

NOE helicopter mission has started. It will be used as a basis to explain the function of each of the four windows.

4.3.3.1 The NOE Threat Scenario Window

The NOE Threat Scenario window is the largest window on the display. It is intended to graphically show the terrain environment for the helicopter. The perspective of the graphics is roughly that of an elevated viewer looking down at the center of the window with a depression angle of 45 degrees. In choosing the scenario, we wanted to expose the helicopter to many types of terrain and obstacle situations so that the rules for flying in these situations would be activated, i.e. a very benign scenario would not trigger most of the rules so they could not be evaluated. Hidden from direct view, but accessible while the demonstration is running, are the terrain data points. As explained earlier in section 4.3.2, these data points are spaced on a uniform 10x10 pixel grid. Based on the perspective, this implies that the distance between the data points is NOT uniform. Writing the rules to compensate for this non-uniform distance between the data points was not performed, so the rules treat the data points as being uniformly spaced in distance. This apparent distortion in the perspective should not detract from the actions of the rules as seen by the evaluator.

Looking at Figure 6, the crosses connected by straight lines running, roughly, from the lower left corner of the window to the upper right corner of the window define the primary route. This route was chosen based on our interviews with the pilots and the Fort Rucker video tape. It crosses every major terrain and obstacle feature of the scenario, and so it is a path to explain what features are present in the scenario. Starting with the straight line connecting the cross in the lower left corner to the next cross, the terrain and obstacle features that each segment passes over, will be described.

The first segment is situated over flat ground with a relative elevation of 20 feet. Both above and below the segment are rocky ridges with an elevation at the top of the ridges of about 50 feet.

The next segment begins over flat ground with an elevation of 20 feet, and with ridges to the left and right. It then moves into a flat open area as it approaches a line of trees bordering a river. The trees are of varying height with an average height of about 25 feet above the ground. The last part of this segment is over the river with a relative elevation of zero feet.

The third segment is entirely over the river. On either river bank, are trees with an average height of about 25 feet. This segment ends just before a wide black curved line representing a road.

The fourth segment crosses over a bridge with a height of 30 feet spanning the river before it passes over some trees on the upper river bank. It then crosses over two thin parallel lines running roughly parallel to the road that represents power wires with a height of 30 feet above the ground. Poles are specified that support the wire.

The last segment is continually increasing in elevation with a final relative elevation of about 145 feet.

With this variety of terrains and obstacles, we can demonstrate the integration of many different types of terrain and obstacle avoidance rules and functions.

4.3.3.2 Information Window

The Information window provides additional information about the state of the helicopter that may not be obvious from the scenario display. It consists of a set of six instruments. From left to right, they are: the radar warning receiver, the air speed indicator in nautical miles per hour, direction indicator, radar altimeter, barometric altimeter, and scaled elapsed simulation time in minutes and seconds.

The radar warning receiver indicates the direction to an emitting threat. It is first shown in use starting with Figure 11. When a threat is indicated on the radar warning receiver the evaluator is informed that the rules that govern threat detection and avoidance have become activated.

The air speed and direction indicators perform just as their names imply. The movement of the helicopter is scaled according to the indicated speed and direction. Currently, the scale factor is five feet per image pixel.

Both a radar and barometric altimeter are shown so that the evaluator can sense that the helicopter is flying over varying terrain, and at the same time see how high the helicopter is above the ground. Height above the ground is an important aspect of terrain masking. The helicopter in this scenario tries to maintain a height of 15 feet above the terrain if the terrain is flat. If the terrain has an increasing slope, it will increase its height to compensate for the slope. No indication of altitude is shown in the movement of the helicopter in the NOE Threat Scenario window; it only shows ground path.

The last instrument shows the scaled simulation time in minutes and seconds. The movement of the helicopter is computed for each scaled second.

4.3.3.3 Control Window

The Control window has five mouse-sensitive words in it that control the operation of the Threat Expert System demonstration. This panel of "buttons" enables the demonstration to be operated almost entirely through mouse actions. The functions of these buttons and how they are used to operate the demonstration is explained in section 4.3.4.3 Operating the Threat Expert System.

4.3.3.4 Query Response Window

The Query Response window is intended for text messages that may help to inform the evaluator. There are several types of messages that can appear in the window. Instructional messages tell the evaluator that he must perform some action or series of actions in order for the demonstration to continue. Automatic messages appear in the window when the helicopter reaches some important decision point. These automatic messages are also accompanied by synthesized voice messages if your site has a Dectalk device connected to the Symbolics computer. Query messages appear when the evaluator performs some action that asks for additional information. Such an action might be mousing on the WHY? button, or asking for terrain information by mousing on the NOE Threat Scenario window.

4.3.3.5 Illustrative Example Runs of the Demonstration

In order to illustrate the capabilities and actions of the Threat Expert System software, some photographs were taken of the evaluation display during the execution of the demonstration. Explanations of these example runs should give the evaluator a better understanding of what to expect when he executes the demonstration.

Figure 6

This is intended to show the straight line path linking the checkpoints along the Primary Route. This is the path the helicopter would take if there were no rules to govern its flight path, i.e. the "no intelligence" base line path. It should be used as a point of reference when looking at the actual path the helicopter takes.

Figure 7

This is intended to show the straight line path linking the checkpoints along the Alternate Route. This is the path the helicopter would take if there were no rules to govern its flight path, i.e. the "no intelligence" base line path. It should be used as a point of reference when looking at the actual path the helicopter takes when it flies along the Alternate Route.

Figure 8

This shows the first 22 seconds of flight along the Primary Route when there are no threats present in the scenario. All of the instruments in the Information window have values in them except for the radar warning receiver which correctly indicates that there are no emitting threats present. An automatic message appears in the Query Response window indicating that there are trees ahead.

Figure 9

This shows the entire path that the helicopter took during the mission. The instruments show that the helicopter finished the mission with an airspeed of 66 nautical miles per hour, a height of 33 feet above the ground, an elevation of 176 feet, and it took one minute and 40 seconds. When the WHY? button was moused,

four messages came up on the Query Response window describing the last four flight control decisions that took place. The PAUSE button is shown in reverse video to show that the pause function is activated.

Figure 10

This shows the entire path the helicopter took along the Alternate Route. An icon representing a known anti-aircraft missile site is shown in the middle, right part of the NOE Threat Scenario window. The closed boundary around the icon encloses the area in which the helicopter can be destroyed. Because the threat boundary encloses one of the Primary Route checkpoints near the bridge, the Mission Routing expert chooses to send the helicopter on the Alternate Route. In the Information window, the radar warning receiver indicates the direction to the anti-aircraft missile site.

Figure 11

This shows the first seven seconds of a mission in which there are two known threats present. The icon being pointed to by the radar warning receiver represents an air defense gun. When known, threat position and type information can be combined with radar warning receiver information, then, data fusion has been performed. This action is indicated in the Query Response window. The anti-aircraft missile site does not show up on the radar warning receiver display because it has not satisfied the detection threshold of the receiver. The detection threshold is a function of the height of the helicopter, the distance to the threat, and a random number thrown in to make it a stochastic process much like a true radar warning receiver. When the radar warning receiver detects an emission from a threat, the threat is flashed to indicate this fact to the evaluator.

Figure 12

This is the same mission as shown in Figure 11, but at 46 seconds into the mission. Notice the deviation in the path the helicopter took, in order to avoid the threat boundary around the air defense gun. The radar warning receiver shows that it has detected both threats now. The radar and barometric altimeters register the same value because the relative elevation of the water under the helicopter is zero. No threats were blocking the Primary Route checkpoints, so the helicopter is following the Primary Route.

Figure 13

This is one minute 13 seconds into the mission. The Query response window shows an automatic message saying that the bridge has been detected and what action to perform.

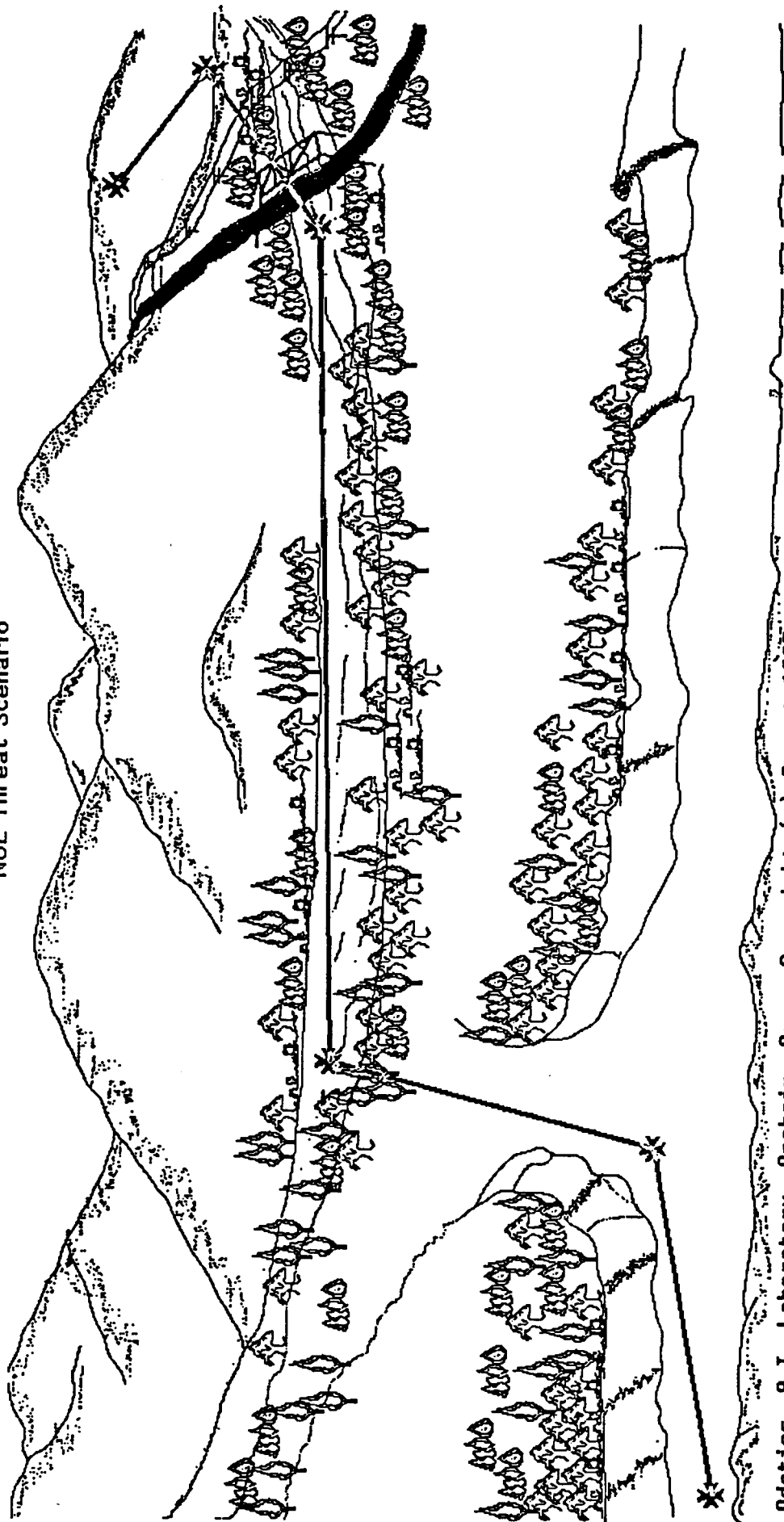
Figure 14

This is the completed mission showing the entire path taken by the helicopter. The radar warning receiver has dropped the indication to the air defense gun and only shows the direction to the anti-aircraft missile site.

Figure 15

This is the first 17 seconds of a new mission. At the start of the mission, two threats were defined, one known anti-aircraft missile site, and one unknown air defense gun. The unknown air defense gun is shown in reverse video to distinguish it from known threats. The Threat Detection expert will try to triangulate on unknown threats using the radar signature of the threat and its direction as determined by the radar warning receiver. If this triangulation succeeds, a default threat

NOE Threat Scenario



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Control

WHY?

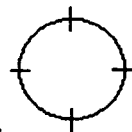
THREAT

START

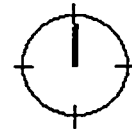
PAUSE

CONTINUE

Information



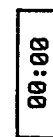
AIR SPEED



ALTITUDE



BARO-ALT



SIMULATION TIME

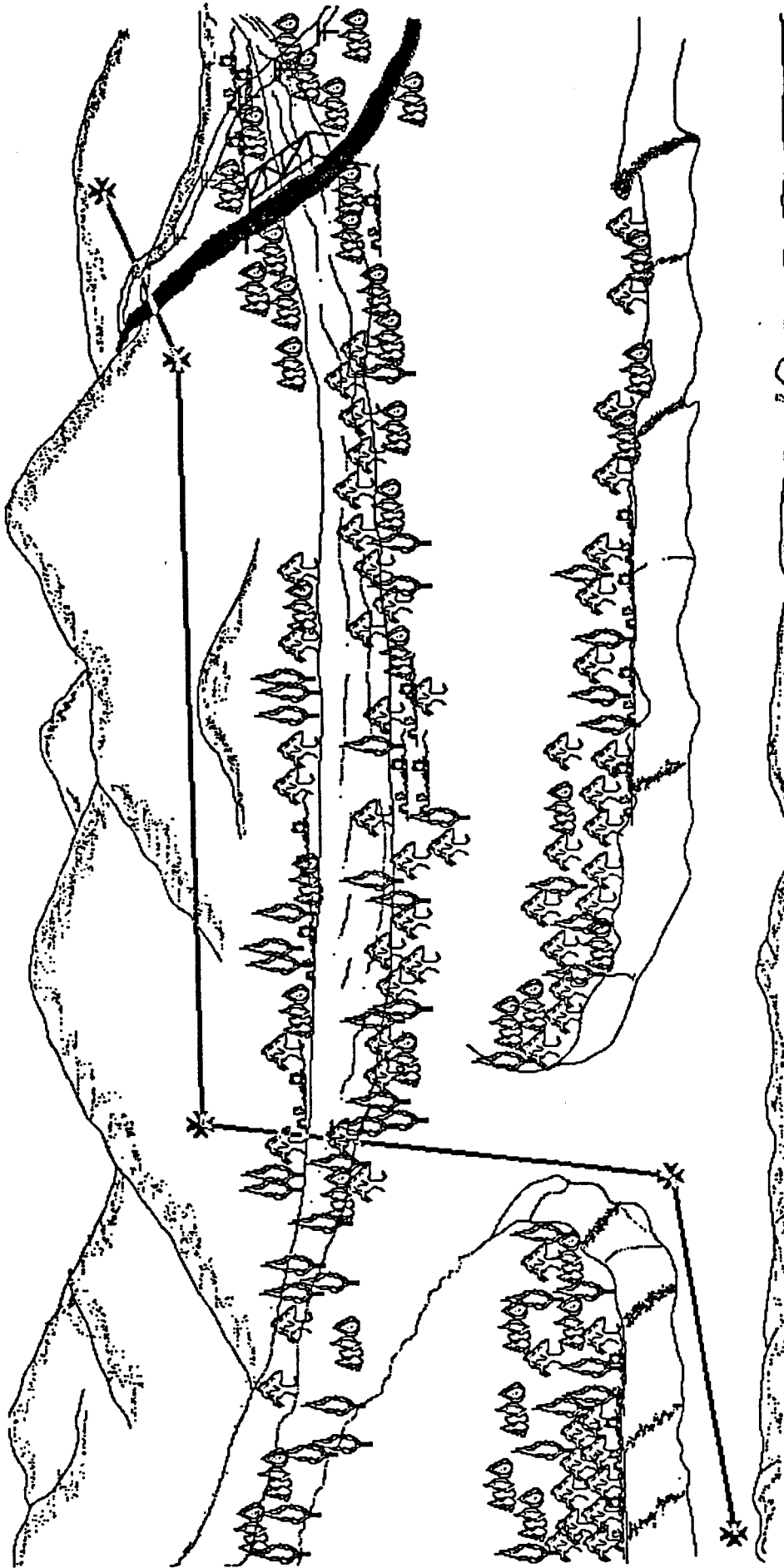
Query Response

Primary route from Starting to Final location.

Distance = 1894 meters.

Mouse-left on CONTINUE

NOE Threat Scenario



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Control

WHY?

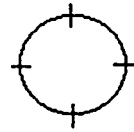
THREAT

START

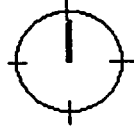
PAUSE

CONTINUE

Information



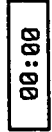
AIR SPEED



ALTITUDE



BARO-ALT



SIMULATION TIME

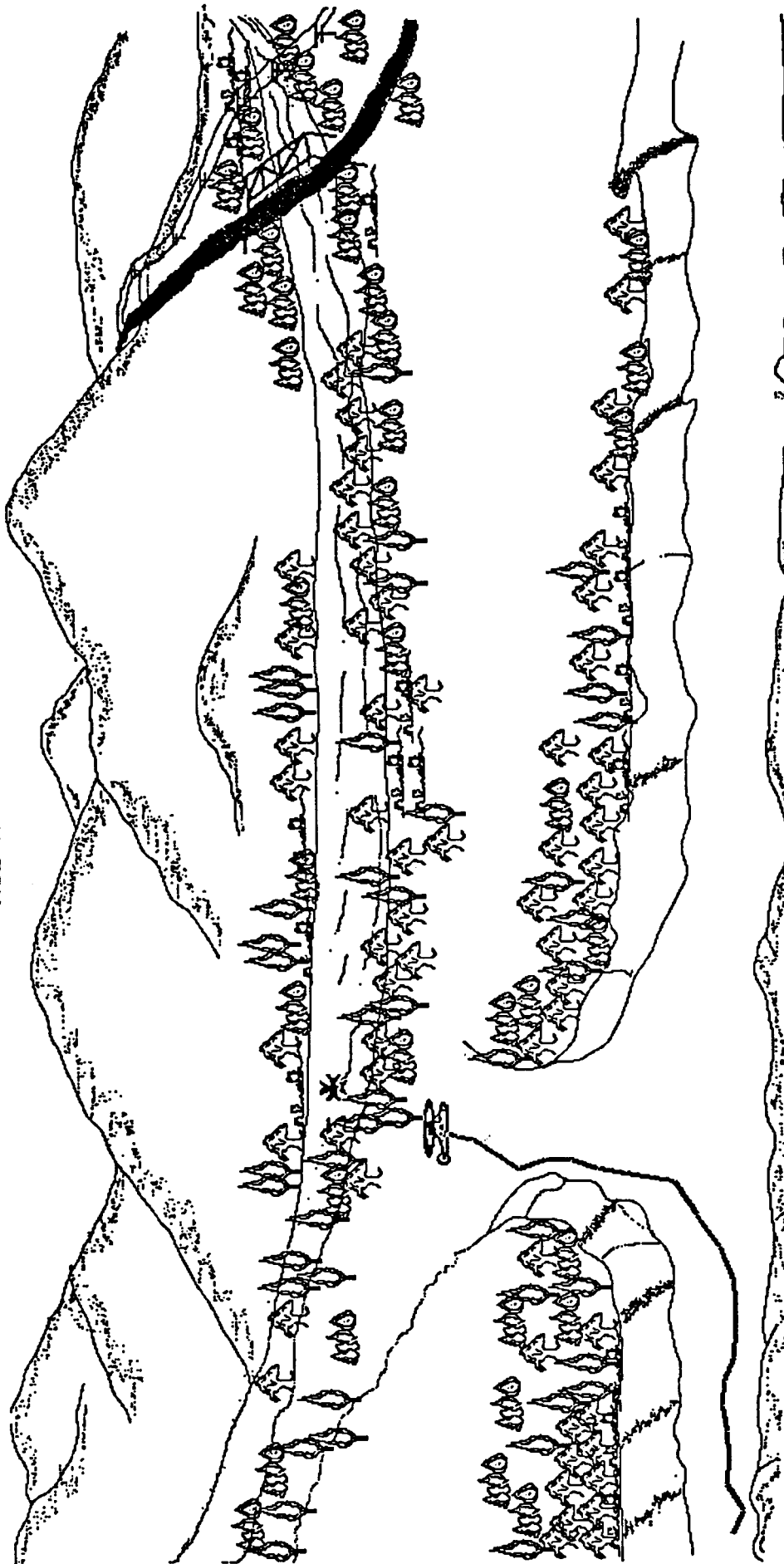
Query Response

Alternate route from Starting to Final location.

Distance - 1754 meters.

Mouse-left on CONTINUE

NOE Threat Scenario



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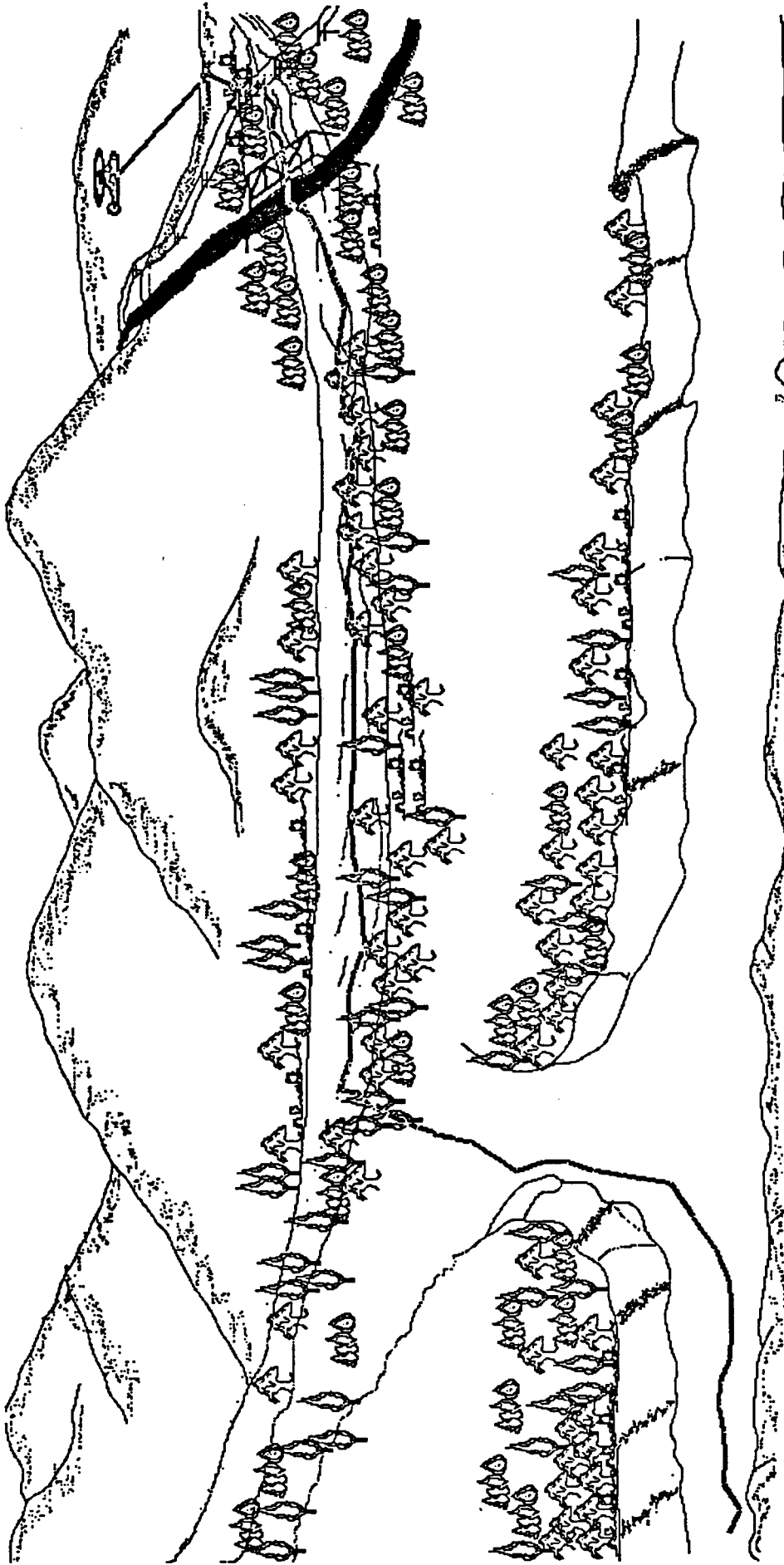
Control		Information			
WHY?	THREAT				
START	PAUSE CONTINUE	30	AIR SPEED	21	ALTITUDE
				41	BARO-ALT
					0:22
					SIMULATION TIME

Query Response

Caution. Trees ahead.



NOE Threat Scenario



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Control

WHY?

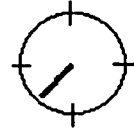
THREAT

START

PAUSE

CONTINUE

Information



66
AIR SPEED

33
ALTITUDE

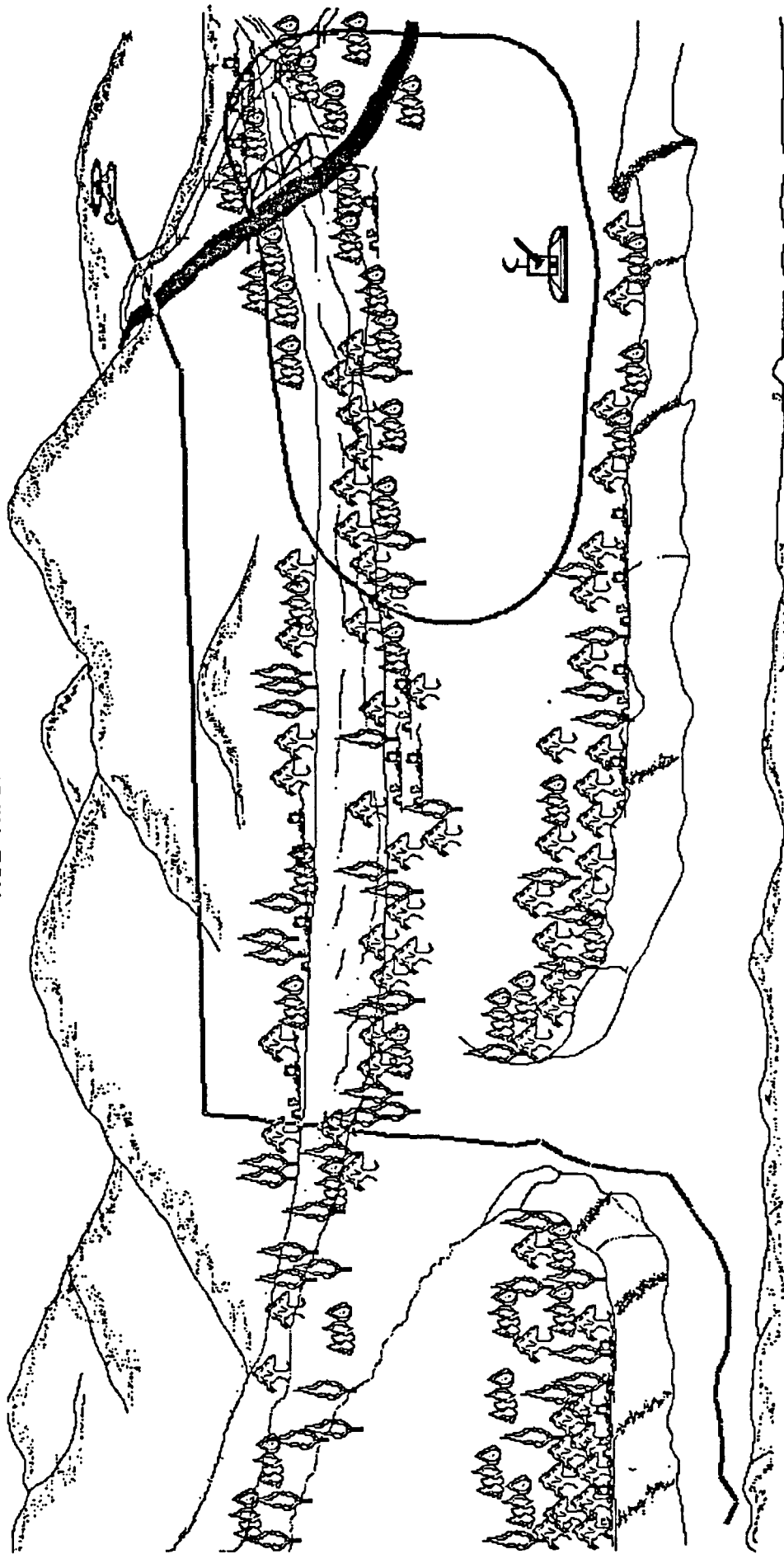
176
BARO-ALT

1:40
SIMULATION TIME

Query Response

- 22 Mission Accomplished.
- 21 Trees blocking path. Find gap or climb over.
- 20 Flying over river. Watch for overhanging obstacles.
- 19 Fly direct to goal while avoiding threats and obstacles.

NOE Threat Scenario



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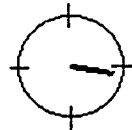
Control

WHY?

THREAT

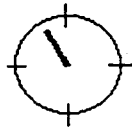
START

PAUSE CONTINUE



36

AIR SPEED



44

ALTITUDE

179

BARO-ALT

1:31

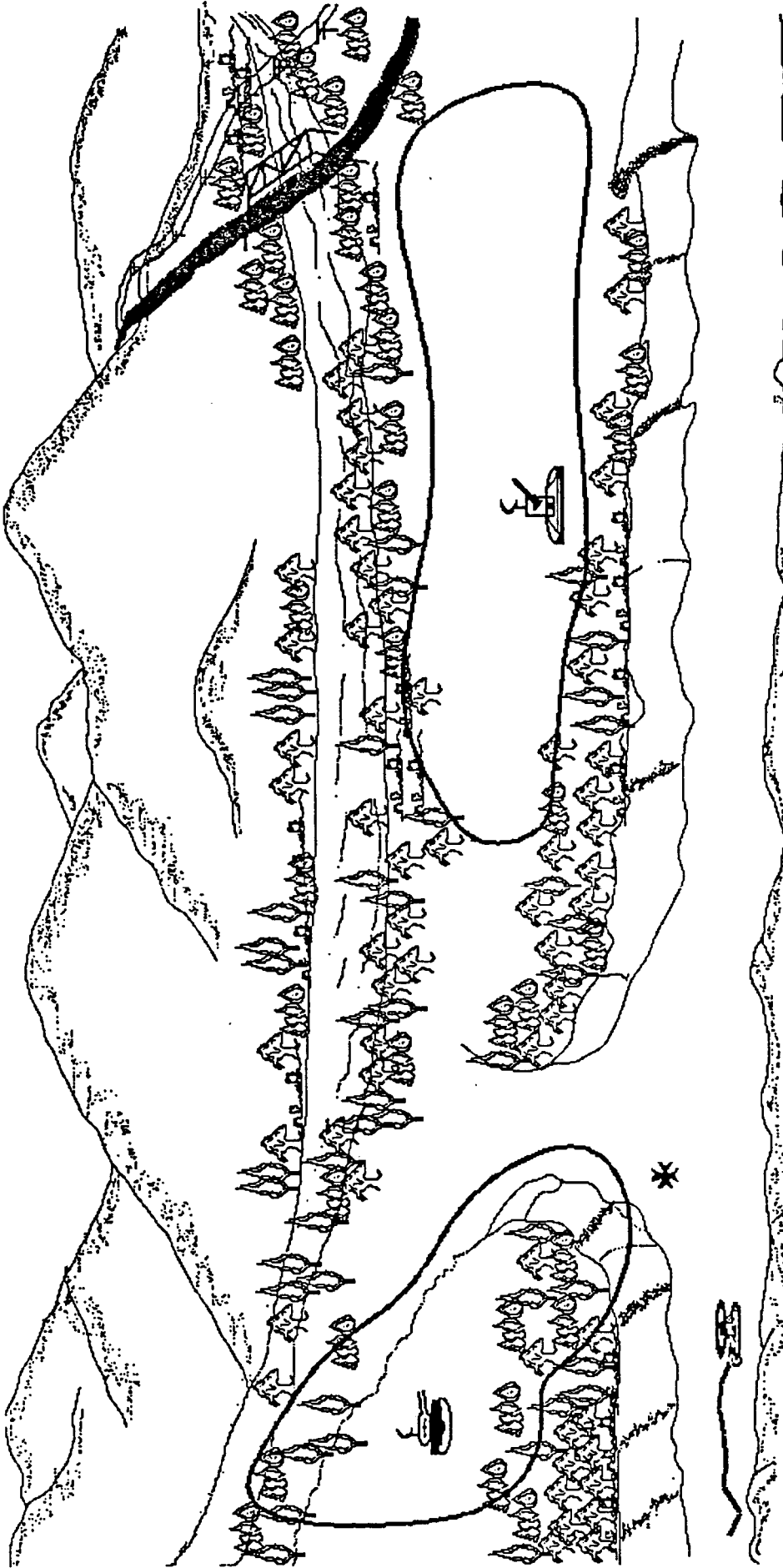
SIMULATION TIME

Mission Accomplished



Query Response

NOE Threat Scenario



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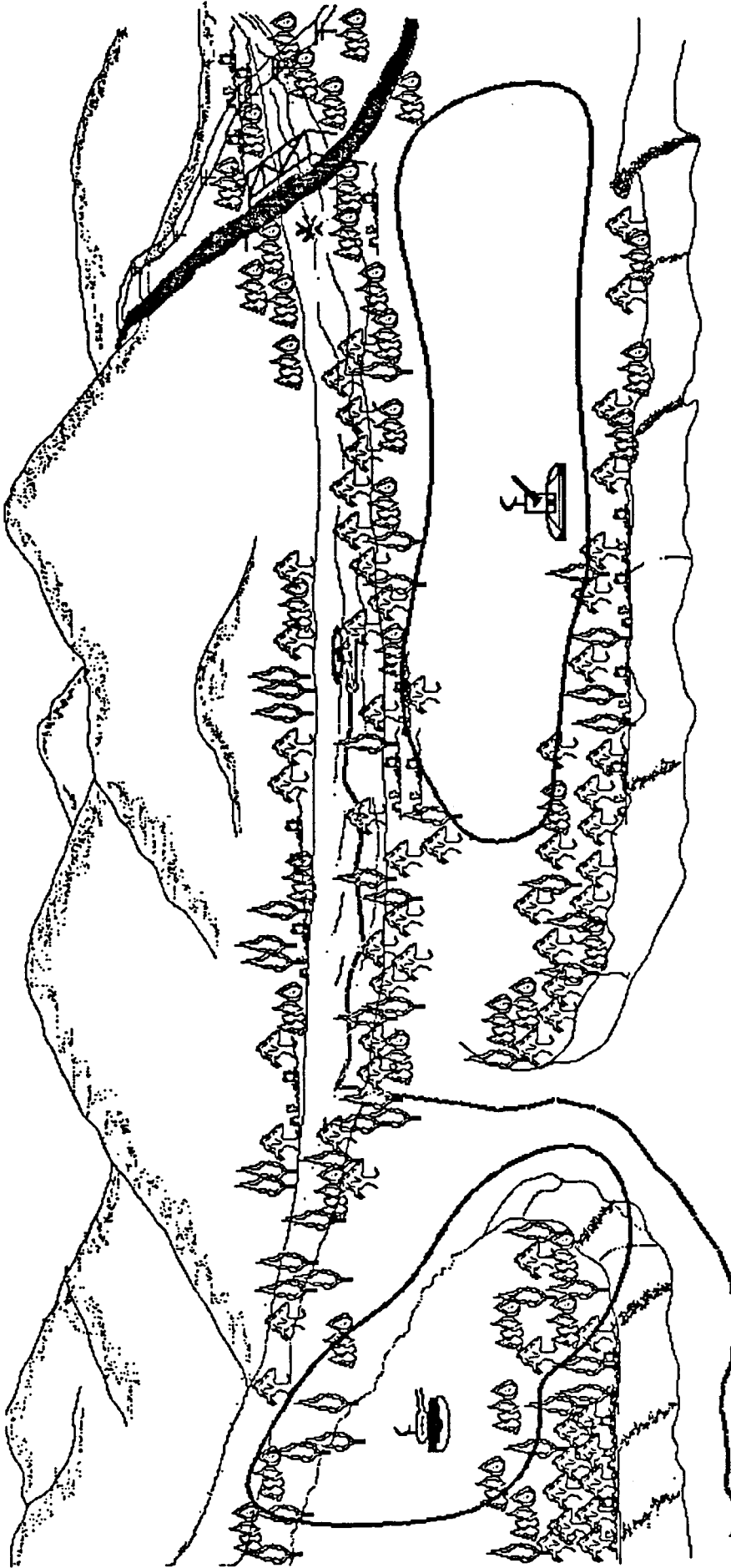
Control		Information			
WHY?	THREAT				
START	PAUSE	50	15	35	0:07
	CONTINUE	AIR SPEED	ALTITUDE	BARO-ALT	SIMULATION TIME

Query Response

Data fusion performed.



NOE Threat Scenario



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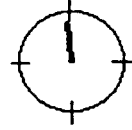
Control

WHY? THREAT

START PAUSE CONTINUE

Information

79
AIR SPEED



15
ALTITUDE

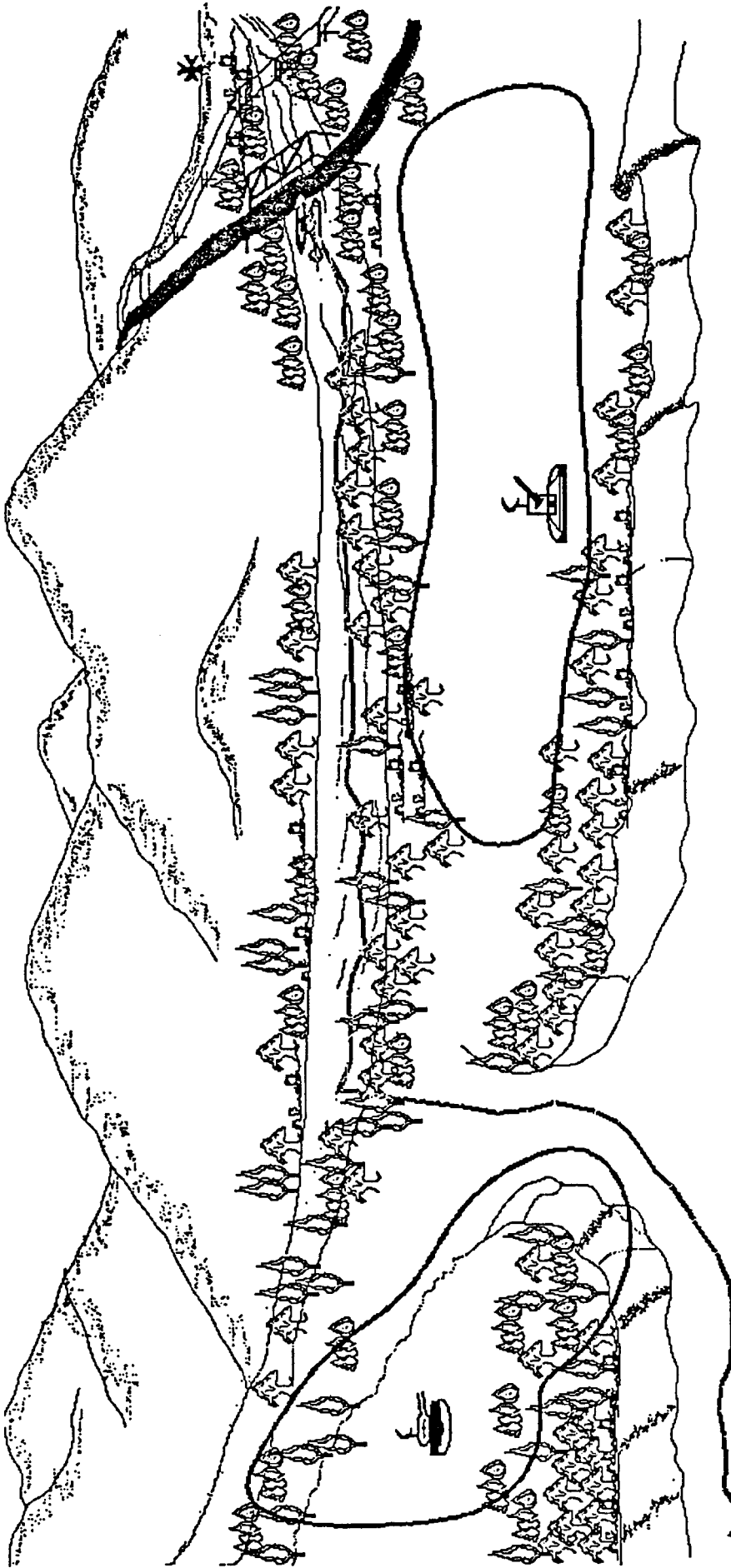
15
BARO-ALT

0:46
SIMULATION TIME

Query Response

Caution. Trees ahead.
 Data fusion performed.
 Caution! Avoid threat boundary. Known threat nearby.
 Data fusion performed.

NOE Threat Scenario



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Control

WHY? THREAT
START PAUSE CONTINUE

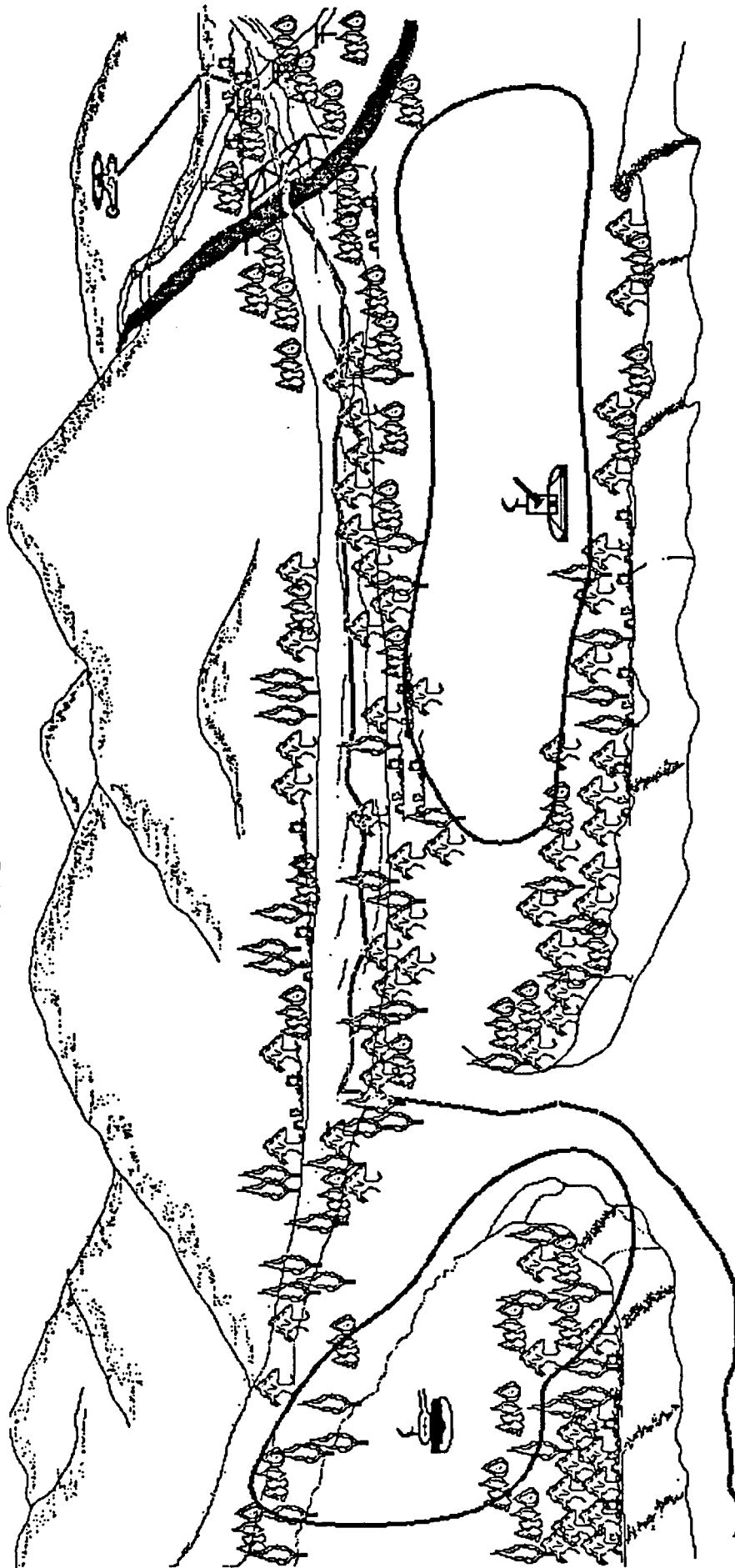
Information

3 AIR SPEED 22 ALTITUDE 22 BARO-ALT 1:13 SIMULATION TIME

Query Response

Bridge directly ahead. Pull up.
Caution. Trees ahead. 
Data fusion performed.
Caution! Avoid threat boundary. Known threat nearby.

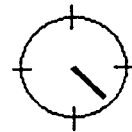
NOE Threat Scenario



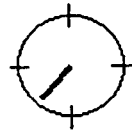
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Control
WHY? THREAT
START PAUSE CONTINUE

Information



75
AIR SPEED



46
ALTITUDE

177
BARO-ALT

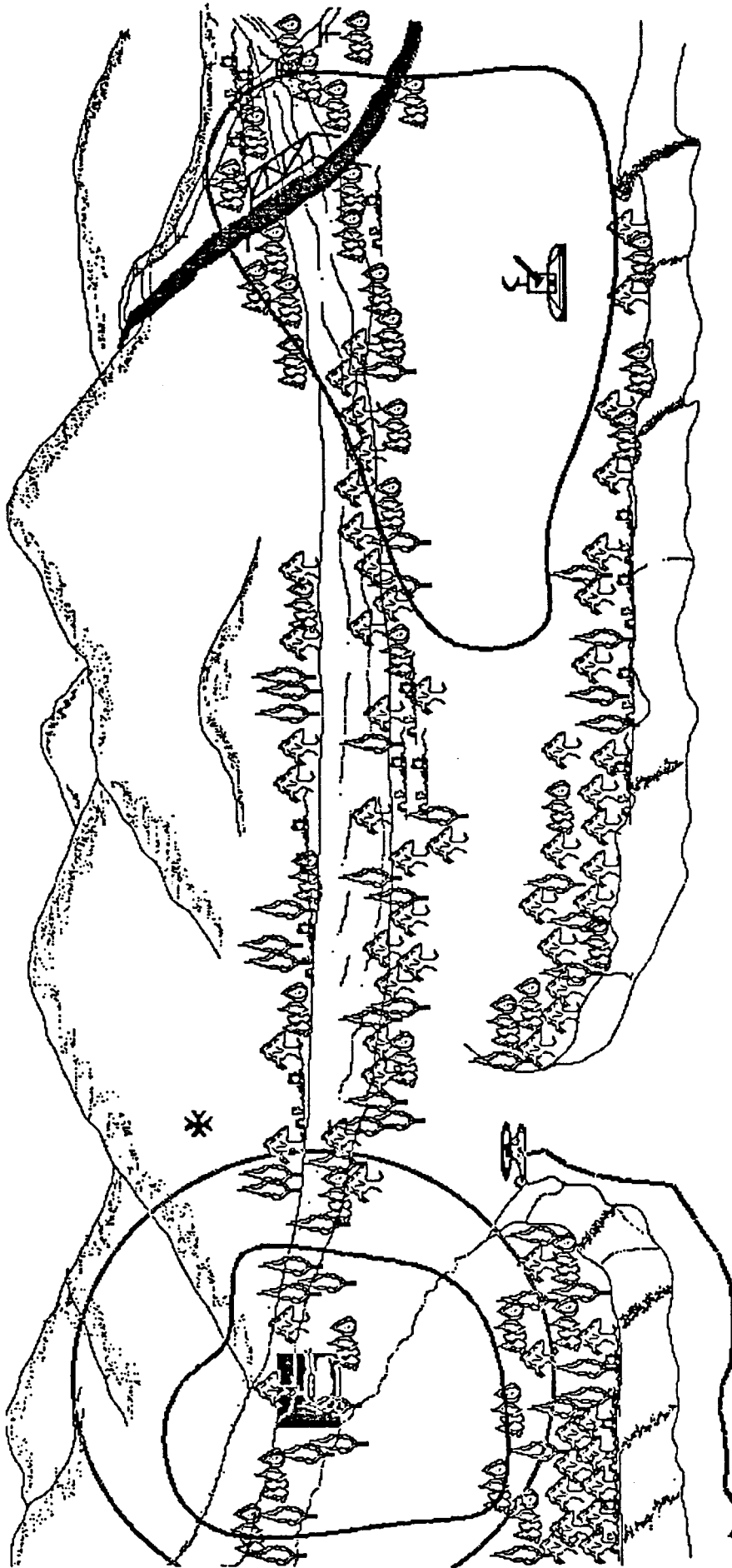
1:44
SIMULATION TIME

Mission Accomplished

Query Response



NDE Threat Scenario



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Control

WHY?

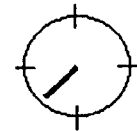
THREAT

START

PAUSE

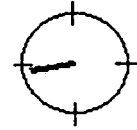
CONTINUE

Information



55

AIR SPEED



15

ALTITUDE

35

BARO-ALT

0:17

SIMULATION TIME

Query Response

Caution! Avoid threat boundary. Observed threat nearby.
Primary path blocked by threat. Switch to alternate route.

boundary for that type of threat is drawn on the display with a circle. Threats that are located with this method are called Observed Threats. The message in the Query Response window indicates an action to take because an Observed Threat is nearby.

4.3.4 Operation of the Threat Expert System Demonstration

The Threat Expert System demonstration is "layered" on top of the ART expert system shell and the software supplied with the 6.1 release world from Symbolics. To successfully load and operate the Threat Expert System demonstration, you must be familiar with these products. The following operating guide assumes such familiarity. There are three phases to the loading and operation of the Threat Expert System:

- 1) Site preparation.
- 2) Loading the Threat Expert System.
- 3) Operating the Threat Expert System.

The steps that are given in each of these phases is intended to be a guide to get the system up and running; it is not intended to be the final word. The user is encouraged to experiment with different configurations and procedures that may work better at your site.

4.3.4.1 Site Preparation

Before the the Threat Expert System can be loaded on to your Symbolics computer, there are several steps required to prepare the computer for the software. These steps are outlined below.

- 1) Since the Threat Expert System is layered on top of ART, you must have ART version 3.0 loaded and, preferably, saved as part of the world that you booted with.
- 2) Check the LMFS space to see that there is at least 700 blocks available for the Threat Expert System software. This should be enough room for the current release of the software as well as any modifications you may want to make later.
- 3) Check the size of the paging files in the boot file that you booted the computer with to make sure they total at least 160000 blocks, i.e. if you booted the computer with the boot file called FEP0:>foo.boot, show the file and add up the sizes of all the *.page files that you specified to make sure they total at least 160000 blocks. Check your Symbolics manuals on how to add more paging space if you need it.

4.3.4.2 Loading the Threat Expert System

This section explains how to load the Threat Expert System software from a carry tape supplied by Odetics into the LMFS, and how to load the Threat Expert System software into ART so that it will be ready to execute.

LOADING FILES FROM THE CARRY TAPE

The general method of loading files from a carry tape is fairly well documented in the Symbolics manuals. This guide should be used to supplement what is already documented in the Symbolics manuals.

- 1) Into a LISP Listener, type: (tape:carry-load) A list of file groups on the tape will be displayed.
- 2) When you see the question, "Load all these files?", answer Y.
- 3) When you see the question, "Load
Katie:>threat>background.art into
new-host:>pathname>background.art? (Y,N,O, or A)?",
answer O. Specify the host, pathname, and filename to
be new-host:>threat>background.art
Where: new-host is the name of your computer.
(Like Katie is the name of
Odetics' computer.)
Pathname is some unknown pathname that the
computer will default to.
Since the threat directory does not exist, it will ask
if it should create a new directory. Answer YES. If
you are already using a directory called threat, or if
you just want to put it into a different directory,
feel free to use a different name. In a later step, a
logical translation file will be modified to reflect
the actual directory you loaded the files into.
- 4) When you see the question "Load Katie:>threat>
background-load.bin into new-host:>threat>
background-load.bin (Y,N,O, or A)?", answer A. About
50 files will be loaded into the >threat> directory.
- 5) When you see the question "Load
Katie:>dectalk>dectalk.system-dir into
new-host:>pathname>dectalk.system-dir (Y,N,O, or A)?",
answer O. Specify the host and pathname to be
new-host:>dectalk>It will ask to create a new directory
dectalk>, answer YES.

- 6) Put the remaining files from Katie:>dectalk> into new-host>dectalk> by answering the next (Y,N,O, or A) with A.
- 7) When you see the question "Load Katie:>dectalk>dectalk-2>dectalk-2.patch-dir into new-host>pathname>dectalk-2>dectalk-2.patch-dir (Y,N,O, or A)?" answer O. Specify the host, pathname, and filename to be new-host:>dectalk>dectalk-2>dectalk-2.patch-dir
- 8) When you see the question "Load Katie:>sys>site>dectalk.system into new-host>pathname>dectalk.system (Y,N,O, or A)?" answer O. Specify the host, pathname, and filename to be new-host:>sys>site>dectalk.system
- 9) When you see the question "Load Katie:>sys>site>dectalk.translations into new-host>sys>site>dectalk.translations (Y,N,O, or A)?" answer A.

EDITING THE TRANSLATIONS FILES

This completes the loading of the files from the carry tape into the LMFS. You must now edit the translation files that were loaded to reflect the new host and path names. First, edit sys>site>dectalk.translations by changing Katie to the new-host name. Save the file. Now, edit threat>demo.translations by changing K: to the new-host name. Save the file and evaluate the buffer to load the new translations. (There is no need to evaluate the dectalk.translations file since it will be done automatically.) YOU MUST LOAD threat>demo.translations EVERY TIME YOU DO A COLD BOOT SINCE THE threat>demo-load.lisp FILE

DEPENDS ON HAVING A TRANSLATION FOR THE LOGICAL NAME
threat:odetics;.

MAKING THE DECTALK SYSTEM

Even if you don't have a Dectalk speech synthesizer, you still must make the dectalk system since the Threat Expert System assumes that such a system exists. To make the dectalk system, type: (make-system 'dectalk :no confirm) and answer Y to the questions. YOU MUST MAKE THE dectalk SYSTEM EVERY TIME YOU DO A COLD BOOT SO THAT THERE WILL BE A TRANSLATION FOR THE dectalk PACKAGE.

LOADING THE THREAT EXPERT SYSTEM SOFTWARE

With these preliminaries taken care of, the Threat Expert System can now be loaded into the ART system.

- 1) Type <SELECT>-A to get to the ART Studio.
- 2) If you have been using the ART system, mouse CLEAR in the root menu to clean out the rule and fact databases.
- 3) If you have NOT COLD BOOTED the computer since the last time you ran the demonstration, skip to 14.
- 4) Mouse LOAD in the root menu.
- 5) Type threat:odetics;terrain-schema.art This takes about 45 minutes to load in.
- 6) Type <CONTROL>-E to get to the ART evaluation mode.
- 7) Type (assert (fill-terrain-array))

- 8) Mouse LOAD in the root menu.
- 9) Type `threat:odetics;make-terrain-array.art`
- 10) Select RESET in the root menu. This takes about 30 minutes to complete.
- 11) Select RUN in the root menu. This takes about 20 minutes to complete. The LISP array called `terrain-array` is now filled with the data that is in the terrain schemata. We can now clear the terrain schemata out of memory so that the ART system will run more efficiently and faster.
- 12) Select CLEAR in the root menu. This takes about 30 minutes to complete.
- 13) If you have about an hour, I would suggest doing a garbage collection now by evaluating `(gc-immediately)`. The above steps create a lot of garbage, and may require immediate garbage collection during the demonstration if it is not performed now.
- 14) Mouse LOAD in the root menu.
- 15) Type `threat:odetics;demo-load.lisp`. When it finishes loading in about 20 minutes, the demonstration will be ready to execute. (If you are loading the demonstration for the first time after a cold boot, a message will appear warning you that RUN is being redefined. This is normal, and should be answered with P, for proceed.)

4.3.4.3 Operating the Threat Expert System

The Threat Expert System demonstration is operated almost exclusively through mouse actions. To start the demonstration running, mouse RUN in the root menu. This will cause the root and command menus to disappear. (Show file threat:odetics; demo-load.lisp to see how the RUN and RESET menu actions have been modified.) Hitting the <SUSPEND> key will stop the demonstration and cause the root and command menus to reappear. (If you are in the ART evaluation mode, you must also hit <META><ABORT> OR use the ART window menu, mouse-left-2, to "bury" the NOE Threat Scenario window to make the root menu appear.)

Once the demonstration is running, it goes through three phases, 1) the start up, 2) threat definition, and 3) the helicopter flight. The start up phase commences as soon as you mouse RUN in the root menu. Messages will appear in the Query Response window informing you about which start up action has been performed and telling you to mouse-left on the CONTINUE button in the Control window to continue the start up phase. The start up phase ends with a message in the Query Response window asking you to either mouse-left on the THREAT button to enter the threat definition phase or mouse-left on the START button to start the helicopter flight. (Look at the mouse documentation line as you move the mouse over the different buttons in the Control window.)

By mousing-left on the THREAT button, you enter the threat definition phase. Messages will appear in the Query Response window informing you on what to do next. Basically, you have to mouse-left at the position in the NOE Threat Scenario window where you want the threat to appear, and then define the threat boundary by mousing-left to establish points on the boundary. Mouse-right will draw in a closed cubic spline connecting the boundary points. Mousing-left on the THREAT button will allow you to define more threats.

The threat definition pop-up menu allows you to choose between two types of threats, Air Defense Gun or Fixed Anti-Aircraft Missiles. You can also choose to have the threats known or unknown before the mission starts.

There are a few idiosyncrasies that you should be made aware of. When you mouse-left on the THREAT button, the mouse icon changes to a cross-hair and moves to the upper left corner of the NOE Threat Scenario window. When you mouse-left to position the threat, you must move the mouse slightly to get the system to pop up the threat definition menu. Likewise, when you mouse-right to finish the threat boundary, you must move the mouse slightly to get the system to draw in the boundary. After the boundary is drawn in, the mouse will be positioned over the THREAT button in the Control window.

Once you have defined all your threats, mouse-left on the START button to start the helicopter mission. As it proceeds through its mission, messages will automatically appear in the Query Response window that have corresponding synthesized voice messages. To have the Threat Expert System explain in a little more detail some of its actions, mouse-left on the WHY? button in the Control window. It will display the most recent four actions in the Query Response window. Mousing-middle on the WHY? button will show the next earlier group of four actions. Mousing-left on the WHY? will always pop back to the most recent four actions. Mousing-left when the mouse is located somewhere in the NOE Threat Scenario window will print the terrain data point closest to the mouse location. Note that valid terrain data is located on a 10x10 pixel grid ONLY along the primary and alternate routes. Outside of this area, a default value of terrain type FLAT-GROUND and elevation 20 is used. Mousing-left on the PAUSE button will stop the motion of the helicopter but still allow you to mouse the WHY? button for explanations. The CONTINUE button

will allow you to continue the simulation from where you paused it.

After the helicopter has reached its final goal, a Mission Accomplished message will appear in the Query Response window. At this point, the demonstration is finished and you must hit the <SUSPEND> button to get the command and root menus back. You can now mouse RESET in the root menu to begin another run of the demonstration.

5.0 RESULTS AND CONCLUSIONS OF PHASE I

5.1 Results

Two main results were achieved from this Phase I research in the Threat Expert System project. First, we have demonstrated the feasibility of the concept for using an expert system to aid helicopter pilots which flying NOE missions in threat and obstacle situations. Secondly, we have developed a basis for continued research in Phase II for applying artificial intelligence techniques to assist and advise pilots in NOE helicopter flight. The modular architecture of the Threat Expert System interfaces with other "experts" and will allow a deeper knowledge base to be developed in each of these modules.

5.2 Conclusions

The concept of using an expert system to aid NOE helicopter flight was demonstrated in three related efforts. Acquisition of the expert knowledge from various sources was the first effort. This was followed by the development of an architecture for organizing the knowledge. Finally a prototype working demonstration was developed to run on the Symbolics computer using the ART expert system development tool. These efforts together demonstrate the viability of using an expert system as a

method of encoding some of the pilot's knowledge so that it can be used as an automated pilot aid.

The experience that has been gained during the Phase I Threat Expert System study forms a strong basis for continued research in this area. Two areas that could benefit from our experience are: real-time extensions to our Phase I effort, and two-dimensional and three-dimensional pattern recognition expert systems for application to NOE helicopter flight.

Developing real-time expert systems is a minimum requirement before any of this technology finds its way into actual flight test. Our experience with the Phase I development effort gives us insight into which of our six experts can be developed into a real-time expert system, and what the impact of new AI technology will be on this development.

It became clear during the Phase I effort that much of the knowledge of a helicopter pilot is based on recognizing two- and three-dimensional patterns. This not only applies to his skill in flying, but also to this ability to plan and execute a mission by looking at a terrain map marked with threat areas. Our experience should help us develop artificial intelligence techniques that can be applied to this problem.

6.0 RECOMMENDATIONS FOR PHASE II

As a result of the Phase I study and in light of the anticipated overall Expert System Development sequence discussed in paragraph 2.3 above the following objectives of the Phase II study are recommended:

- o The integration of a prototype Threat Expert System Advisor into the real-time CSRDF Simulation at NASA Ames.

- o Preliminary definition of the functional requirements for the pilot and sensor interfaces.

The second objective will be met as part of the accomplishment of the first objective, since the successful integration of the TES into the simulation necessarily involves the development of an adequate and compatible pilot interface (both controls and displays) and at least a simple simulation of the sensors and their interfaces with the software. Meeting the first objective entails two additional tasks: 1) the expansion and revision of the Threat Expert System rule base defined in Phase I into a larger but still limited set of rules which are directly applicable to a set of representative combinations of scenarios and threat configurations and 2) meticulous coordination with NASA and the CSRDF simulator principals to define the required hardware and software interfaces with the simulator (including the experimental pilot display/control interface) and to assure the timely implementation and verification/validation of these interfaces.

A Phase II proposal will describe in detail the proposed Phase II effort.

APPENDIX A

April 6, 1987

This is a partial transcript of the four tapes recorded during our interview with Grady Wilson, NASA test pilot. Some of the extraneous conversation was not transcribed, but can be heard on the original tapes. Attending the interview were: Lloyd Tripp, George Westrom, Ellie Kurrasch, Merlin Hoyt.

Tape 1. (Misc. conversation regarding decision tree vs. optimizing functions) (Grady) On your black box concept there, some of it may not be as far away as you think. The Avionics Lab at Ft. Monmouth are working with digitizing maps. Instead of going into an area and asking for a (60 by N ?) map, you go in and pull out your cassette and take it with you. This I think will work with helicopter missions as well. We are limited to a range of 200 miles at most, out and back 100 miles. This is about as long a legs as you have. I don't know how far along they are. I've seen the ads in the books, like everyone else, showing this contouring with - I don't know - coloring. This type of database is going to have to go into your type of machine for the terrain. Normally, that's not going to be as fluid as the man-made devices. The man-made devices will change drastically. The actual battle scene especially. The terrain of the hills, valleys, the creeks, and this type of thing, I think, will be stable enough so you can depend on that. The avoidance of man-made obstacles will have to come from some sensor.

(Ellie) We are going to assume that there is a detector that will give us those obstacles for the period of this knowledge acquisition. We are going to assume that there is a detector whether it is the co-pilot sitting with you that says "There is a wire over there," or something else. We are not going to assume what that detector is.

(George) A kind of a key point that we want to make here is that this is Phase I. The only thing is that we have to convince the customer that we should go onto Phase II. The thing we want to answer is, "Does this make sense?" If the answer to this is yes, then we want to produce enough evidence, graphical, heuristic, and so forth, to convince the customer that it makes sense. If the customer agrees, then we go onto Phase II. We don't have to cope with all the problems. Also, the time frame for Phase II is two years. So, making assumptions about technical developments between now and then, for example, in the sensor technology - there will be better sensors available - so, making certain assumptions makes sense. We're talking about something that is not going to be implemented in less than four years, that's optimistic.

(Ellie) Three or four until it gets into the helicopter.

(George) We are looking into the kind of technology that can be meaningful four or five years downstream. That's the kind of projection that one should have here in the work we are trying to do right now.

(Ellie) With that, why don't we get the chart. Lloyd why don't you explain how we are going to progress with the questioning.

(Lloyd) I want to first describe the scenario. The questioning will be in three phases. One, being along the line of flying through the the scenario without any obstacles in your way - just trying to negotiate the terrain. We've got three or four different terrains in this scenario. Secondly, we want to add in some natural and man-made obstacles and how you would maneuver around these obstacles in the different terrain areas. And finally, add in threats in the different terrain areas. What's the best way, in your experience, to avoid these threats. The things I am looking for when I ask you the

questions are kind of along the line of... We need definable steps. There can't be any hard steps, I know. An example, if your driving your car and you are approaching an intersection with a yellow light. You make a decision to stop or go, but what are the steps you make in that. That's what I want to know. Maybe, you look at your speed, your distance to the intersection, how long the light has been yellow, make a mental calculation about whether you can make it at that speed, and then if you can't, then you step on the gas or hit the brakes. So, actually you have several intermediate steps before you finally decide to actually stop or go. I'm trying to elicit some of those intermediate steps so that if your decision is to pull up. Why did you pull up? Is it because the helicopter has better performance pulling up? Do you feel safer pulling up? There is any number of reasons that you can probably think of. Not only do I want the final action to pull up, but were there any other thoughts or calculations you made in your head. Those are the things I am trying to dig out.

(George) One of the things that is sometimes helpful ... (Put yourself in the situation of teaching a novice pilot)

(Grady) (side remark) After a while, flying becomes more of an instinct.

(Lloyd) Looking at the map, we want to cover most of the terrain going across the map. So we are looking at starting at a point on this side of the map (Pointing to lower left corner). The size of the trees is not proportional. We want this ridge to be high enough so that you could fly below the top of the ridge. Also, we want this clearing to be larger — something that takes a few minutes to cross to get to the creek bed. You will proceed somewhat down the creekbed so you can cross this road or bridge, and then appear at point B — just saying that we want to cross these wires and so on. On the other side of this hill, is where our expected targets are going to be. We want to position ourselves so that we can look behind this hill.

We have this one major path. We envision this to be our preplanned mission. Something that would move along the ridge, between the gap, down the creek to point B. We also envision alternative paths. Maybe continue down the ridge to possibly swing around off the map to get to point B. I am going to deal first with this path here. Does it seem like a likely path to move along the ridge?

(Grady) One thing you want to know first, and probably foremost, is, have you gone that way before? Is this the first run you're making at this thing, because you don't repeat runs. If you do, you're dead. They will set it up on you. They will either string wires or they'll set up the small arms. We found this out very quickly in Viet Nam. (Lloyd) (Interjecting) We'll say that this is the first run. (Grady) In the first encounter with the heavily armed folks in this Lam San 719 I told you about last time, we had always done the routes and they started through with those with something like 60% of the guys either didn't come back or got the hell shot out of them. The casualties were phenomenal because they set up on the side of the ridgeline, and by you going down this... You are well masked, but you've also given him one heck of a good field of fire along the edges. He can set up, and if he knows you are coming, you're dead. This is even more critical if you are taking a fairly well defined path. If you are going to slip through the trees, you are a little better off because it is not as well defined. Because if you have a well defined path - and this is normally the way you'll go if this is a first trip. You pick the stuff that's well defined because of the navigation and this type thing. Assuming that this is the first trip through, that you are in relatively low threat environment, the troops don't know you are going through, then this is perfectly valid.

(Lloyd) The first half of this, there is no enemy beyond the hill.

(Grady) Or that there are just a few troops here (pointing to the open area) and you know you are not going through a base camp or something. So, yeah, that's valid, if you make those assumptions.

(Merlin) Those are the assumptions we're making. That the enemy is beyond this ridge (pointing to the back of the map) and this was fairly safe territory, and this valley may be questionable or something.

(Grady) I don't think in future land battles you will have a well defined trench is ours and that's theirs but, you will certainly know the general area I believe.

(Ellie) Is that left up to the pilot before the mission?

(Grady) Yes.

(Ellie) It's not predefined?

(Grady) No. You leave it up to the pilot. He will take his threat briefing and his objective area, and he'll do the planning himself.

(Merlin) So, we are assuming he has done this, and this is the best route for this particular mission.

(Lloyd) Assuming this ridge is high enough to fly below, say 50 feet, and this is a flat plain. How would you fly this segment from here (point A) to this gap? You would fly right close against the ridge here?

(Grady) You would stay in close to the ridge line, and probably keep your airspeed up, 60 Knots or something. Assuming it's fairly clear here, you are going to stop before you come around the curve, and sneak around the curve - take a look - to see that it is clear here and then you would probably increase your speed again down this way until the next place you can hide or feel safe in masking yourself to look around.

(Lloyd) So, when you are flying this segment, how high do you think you would be flying? Would you tend to stay low?

(Grady) 10 feet at most.

(Merlin) Would you tend to stay just below the ridgeline or down near the bottom?

(Grady) I would keep my rotor masked. This 10 feet comes from the survival aspects of the Indonesian failure. If you are too low, and you loose your engine, you'll stick your tail in the ground when you flare. You've got to kill your airspeed before you set it down so you've got to flare. If you're too low and relatively high speed, 60 knots, you've got to rotate, and you'll rotate the tail into the ground. The only choice you've got then is to pull collective and pop up and kill your airspeed and let back down. If you do that, you'll unmask. So keep just below the ridge to keep your rotor hidden.

(Lloyd) How close do you fly to that ridge? If the ridge was fairly smooth, do you tuck in close or do you want to stay away from it?

(Grady) No, you want to stay away from it. You stay away from it. The rotor tip is very hard to see. You can see the disk, a blur, but it is not easy to judge depth. With a

smooth hard surface, you want to give yourself more. You can take a small strike with a branch, that's common place. Normally, you just have to change the tip cap on the rotor, it's not catastrophic. If you hit the ground, or something solid, you've just lost it because it'll come apart on you. The more solid... in terms of your steps, how bad I think the threat is, will determine my height. How solid is the ground or object, is going to determine my distance out from it, and the speed is going to determine that. The faster out, the more tolerance you give yourself going out.

(Lloyd) The 60 knots, that's probably your peak speed?

(Grady) Unless there is an awful long open space that I've got to get across. Several reasons, first, to accelerate to that speed is an aggravated maneuver. You've got to stand it up on its nose, that's not a comfortable feeling, because if the engine fails, you've bought it because you can't rotate back. So, if you're down in the trees, 60 knots is about as fast as you want to go.

(Lloyd) So, when you get to this gap, you want to slow down way low and kind of peek into the gap?

(Grady) Yes, you've got to slow down starting back here and come around this corner. You'll feel fairly comfortable that there is not anything further down the ravine that's going to hurt you because he would have already opened fire. So, you feel comfortable in your line of sight. As you come around the corner, your looking for obstructions and enemy situations.

(Lloyd) Would you stay fairly close?

(Grady) Yes, as I slowed, I would tuck it in closer to keep them from seeing you, assuming he is down in the valley some place. Again, I would try to keep it below the ridgeline all the way around. At least keep the canopy masked if you can't get the rotor masked, because the canopy glint is probably the first thing you detect, and then the glint off the rotor.

(Lloyd) Looking into the open area, and you see that it is clear, do you pick up your speed here.

(Grady) Yes. If I knew I was going down to the right, I would come around the corner here and clear myself, and then I would go to the next masking position as fast as the distance would allow - 60 knots or something like this - and stop again behind this tree. It is a run and hide type of operation from one spot that you can be obscured to the next spot.

(Lloyd) Sounds like you are varying your speed a lot.

(Grady) Yes, it is continual variation from one hiding spot to another. Around this corner, behind these trees, you would be very cautious of a stream line if you were going down this side (lower side) if this is wide enough. If the stream was wide enough to give the bad guys a view from the other side, you would have to be very cautious going down the side because you've got a long open stretch where he has an excellent field of view. I would increase my speed as much as I could because you are wide open from the other side. You are a lot safer if you have an enemy in the wooded area here (above the ridgeline) because his time of observation is so short that he won't have time to acquire and fire. You are looking at something less than 15 sec for a ZSU-23-4 or the radar guided stuff. But even that, coming through the trees,

he won't have that kind of time.

(Lloyd) If this river was more thickly tree lined on both sides, would you want to hop down into the ...

(Grady) Yes, I think I would. If it were wide enough to get my aircraft and my rotor down, then I can pretty much assume that he has got the same obscuration from the trees on both sides then I would hop down into the river and stay low. Again, next down to the bridge and hold up.

If I felt fairly secure from the threats and I didn't think there was anything big on either side here, I would probably pop over the bridge. You can do that quicker than go around. Then you get down into the creek bed or behind the trees.

Power lines present another problem. 90% of the time I would go to the pole and go over the pole because you just cannot see the lines. Most helicopter pilots will go to the pole, because there is always that top strung line that you are not going to see. You can see some of the heavier lines, but the top one is so small you just can't see it. Go to the pole, pop over it, and run right down the side of the line.

(Lloyd) If this (the stream banks) was fairly heavily tree-lined, but you could still fit your helicopter through, would you go along the bank until you found a gap, or would you go ahead and pop over ?

(Grady) I would stay low.

(Lloyd) So you would go ahead and take the time to make the maneuvers?

(Grady) Yes, take the time.

(Lloyd) Getting up next to the road, would you follow it as a land mark, or would you stay away from it?

(Grady) I'd stay away from it. I'd follow the general profile of the road, but I'd keep my distance, because that's where you expect them to set up. If you had something like this treeline here, I'd stay behind the trees.

(Lloyd) Back over by the ridgeline, if you had an outcropping of rock that went about half way up , so that you could stay masked, would you pop over it or try to bank around it?

(Grady) At these low altitudes, you are better off to pop over it rather than bank around it. If you are trying to bank at that low altitude, you'll tilt that rotor plane and put it into the ground. So if you can still maintain fairly good masking, you are better off popping over it. If you want to go around it, you'll have to stop and rudder turn it around the obstruction and keep it flat.

(Lloyd) If you had a rough ridge with outcroppings every few hundred yards, would you try to keep it close, or take a smoother path around?

(Grady) It depends on the threat environment. If I thought there was someone along the ridge, then I would keep it close. If I didn't think it was a high risk environment, then I would take the smooth route. It's a high workload and you have more chance of sticking the rotor.

(Lloyd) Sounds like you are more comfortable with pulling rather than banking.

(Grady) You are. The only thing you have to worry about with pulling is sticking the tail rotor. It is a practiced technique to rotate about the tail rotor rather than the center of gravity called a quick stop maneuver. You come back on the cyclic, and start to rev the engine, then pull collective which increases lift and allows you to lift the tail. If you just pull back on the cyclic, you'll rotate about the C.G.

Yes, you feel better with pulling rather than banking, because it is something you practice. It will cost you your masking especially if you are above 60 knots. If you are below 40, its not that big of a deal. If you are 5 or 10 feet above the ground you can slow the aircraft by rotating about the c.g. without sticking your tail rotor.

(George) How do you trade off risk verses time?

(Grady) (General answer) You normally do not want to subject yourself to any more risk than you have to. On some med-evac, you might increase your risk, but for normal missions you don't unless the mission is so important that it calls for additional risk.

(Lloyd) How narrow of a gap do you feel comfortable flying through?

(Grady) Most helicopters have a rotor diameter of about 50 feet, some much larger. I would want at least 10 feet on each side, and then I'd stay damn slow. Only if it is well defined, I would not take it down a tree lined creek, because the wake from the rotor vortex will pull the trees in.

(Lloyd) If the clear area had isolated trees...

(Grady) I would stay low and move from one to another and go around them.

(Lloyd) You would not hop over them.

(Grady) No. Most of the time you are operating with a heavy load and don't have enough power to hop over. If you are going to go over a tree, you are going to have to go over slow. The normal maneuver when you pop up is to go slow so you don't overshoot on the up side. If you think there is something on the other side of a (unknown), then you want to give it all you got to get over as quickly as possible to minimize risk. Risk being exposed time.

(Lloyd) If there was a tree branch over the creek, but with enough room to get around it. Would you go around it or pop over it?

(Grady) I would pull up enough to get the rotor over and keep the fuselage down. It is common to go through a gap with the rotor above the gap and the fuselage in the trees.

(Lloyd) If there was room to maneuver around the bridge, would you do this instead of popping over even though it would take more time?

(Grady) In terms of putting it into your computer, I would first consider the threat, then my airspeed. If your airspeed is high and I have slipped up too close to this thing, then you would almost eliminate the option except going over. Probably, can not make a turn or get it stopped. Your distance and your air speed are two determining factors

on whether you go over or not.

(Lloyd) If the threat is high?

(Grady) If you are in a high threat environment, I would make it a point to keep my air speed low so I can get down to the last point I can possibly hide and then I would probably pop over it because I can do it quicker - even though I am exposing my self - than I could go around it. You are allowed to accelerate more quickly if you go over it, while if you go around it you won't be able to stay low. I would bob over it and accept that risk.

(Lloyd) If you were coming down the creek quickly and the threat was low, would you take a nice long lead to get over it or would you slow down any way?

(Grady) Yes, if the threat was low I would do a cyclic and collective climb and pull the nose over, otherwise I would come down rather slow. If your airspeed is low, a cyclic climb won't work, you need 40 to 60 knots to be effective. (He defines a cyclic and collective climb)

(Lloyd) If a bridge suddenly appeared, what would be your reaction?

(Grady) If I feel fairly comfortable with my masking, I'm going to stop and try to peak around this thing. If I've got enough air speed and altitude, I'm going to try to stop it and take a look.

(Merlin) Your priority then is to keep masked and take the time to analyze the situation.

(Grady) Yes.

(George) What about cables? Is that a concern?

(Grady) Yes it is a big concern. The commo (communication) wire is especially bad. They have wire strike systems which are cutters. If you get it on the nose, it will pull the wire up into the cutters. You cannot get it up by the rotor though so it is still a big problem. Talking about sensors, this is not is not a developed technology yet.

----- End of Tape I -----

(Some questions are not on tape I or tape II. I will fill in the answers to those questions from memory.)

(Lloyd) How would you react to seeing troops in the open area?

(Grady) I would take a different path if I could. You assume that they have shoulder launched IR missiles, especially if there is armor around. I would dash from cover to cover so they could not get a fix on me. The sound from the helicopter will alert the troops to your general direction but not enough to point their missiles. Also, I hope they will use some kind of visual identification before firing, since their helicopters will be operating in the same area. Would not risk flying over them or exposing myself even if I thought I was out of range.

(Lloyd) If there is a known ADG or SAM in range or out of range, would you accept

some amount of risk and expose yourself?

(Grady) SAM's are no problem. They operate back behind the lines and can't see you because you operate so low. You won't know about the ADG's because they are mobile. If I had an intelligence report about a known ZSU-23-4, I would avoid the whole area.

(Lloyd) How would you handle a confrontation with another helicopter or fixed wing aircraft? (This is on tape IV)

(Grady) About the only thing you can do is fight it. The Soviets have developed helicopters whose mission is to kill helicopter. Our Cobra and Apache helicopters are equipped with air-air missiles. The scouts also have two Stingers for defense. NASA is doing some simulation of helicopter dog fights because this will be more important in the future. Fighting the helicopter threat must take highest priority because he can come after you. The gun encounters are more like random events that you really can't do anything about any way.

Fixed-wing are usually no problem because you can outmaneuver it. He also cannot stop and get you if you are hiding like the helicopter. The Harrier jump-jets used their ability to stop very effectively against conventional jets during the Falklands War.

--- Start of Tape II -----

(Lloyd) Do your tactics change depending on whether you are flying a scouting, attack or rescue mission?

(Grady) Yes. Scouting exposes himself more, on the other hand he compromises the mission if he is seen so he has to strike a delicate balance.

Scouts will usually be part of Hunter-Killer team. They will start out separated and will stay separated as much as the communication allows. You can usually communicate with someone in your general area, but as far as talking with headquarters about a threat update, you won't get that until we have a relay satellite. You are just too low for the UHF and VHF to work; they are line of sight.

(Lloyd) Do rescue helicopters normally fly NOE missions?

(Grady) Everything, even cargo with sling loads. You just have to do it for survival. Absolutely.

(Ellie) Do scouting helicopters have any kind of defense?

(Grady) The AHIP-50D will shortly mount the Stinger air-air missile, but as far as any air-ground, no.

(Lloyd) The last question relates to how your tactics change as you get near enemy territory, but I think we have covered this earlier.

(Grady) Decrease your speed, increase your masking time. You just become more conscious, sneak around more. You are probably working a 100 mile radius of operation. In a high threat environment where you are sneaking from tree to tree, it is less because this consumes a lot of fuel. Most will have 2 hours or less. At 50 knots, we

talking about 50 mile radius.

(Lloyd) That is all of my questions about the scenario. The rest deal with more general questions. Does anybody else have questions about the scenario?

(Merlin) Do you try to identify areas that may require an alternate path during the mission planning?

(Grady) Yes, you would hope to have several of them at different points throughout your reading.

(Merlin) So you would get up to a decision point, slow down and decide which path to take?

(Grady) That's right. You have a decision tree at each point.

(Break in flow. Grady now describes a Radio Frequency Interferometer, RFI, sensor) It's 360 degrees broken into, I think, 45 degrees. It will point an arrow to the quadrant where there is a threat. It has some buttons that tell you the type of threat and, I think, some kind of audio that goes with each one of these. The Mohawk had one of these systems with 6 or 7 audios. This is very confusing when you're scared any way. Voice interactive may come in to prioritize the threats. It would tell you if he was in search mode, locked on, or launched. Almost certain that Apache has it too. Most of it will not be effective because you will be under the fan of the radar. Now the ZSU-23-4, you won't be, but I'm afraid that his reaction time is so small that it will be all over any way by the time you get the signal.

(Ellie) Do you think that this is a valid scenario?

(Grady) Yes. I think this is a valid choice. Since this covers so many terrains and threats, as an example, I think it is valid.

(Ellie) Is there anything missing?

(Grady) No, you have everything. The type of flying is highly dependent on the type of terrain.

(George) What is the stopping power of the helicopter?

(Grady) It all depends on how high you want to pitch it up and how much power you've got. When you pitch it up, you'll stall and you need the power to arrest your sink rate. It's mainly your speed and power. You can convert on altitude and airspeed, but going at 40 to 50 knots it will take about 100 to 150 yards.

(Lloyd) Do you use any sensors to augment your vision during daylight?

(Grady) No. At night they use the FLIR and low-light TV. The TADS, target acquisition and display system, has a laser ranger for Hellfire missile targeting. The night vision system is pretty effective, but you have to further decrease your speed because you lose your depth perception. (He describes the helmet mounted display)

(Ellie) Would you fly the mission the same way at night?

(Grady) No, I would increase my tolerances. His vision is also reduced so the only

thing you have to worry about is the big radar guided stuff. In a night time environment, you would kick up above this gully but stay down in the wide openings, so you are under his umbrella. You would certainly not tuck it down into that creek because you just can't see. Stay at tree top level. You would not be able to see the wires at all at night, and probably not see the poles. You would almost have to limit yourself to the 100-200 foot level where you're above the wires.

(Lloyd) What is your field of view?

(Grady) In an attack helicopter, more than 180 degrees horizontal, probably 30 degrees back. You'll have blind spots because of posts, but that's all. Excellent field of view in Cobra and Apache. In the Blackhawk, the field of view is not as good. The posts are bigger.

(Merlin) What about armor?

(Grady) Wraps right around you.

(Lloyd) What kind of instruments do you use?

(Grady) Mostly use vision. The pilot is outside most of the time. There is a doppler radar altimeter straight down. Caution lights tell you to look down. You judge speed by "feel" not by instruments.

No warning for detection of objects around you. How you would present such a warning to the pilot is another question.

(Lloyd) Does the pilot worry about navigating, or just leave that to the co-pilot?

(Grady) You try to keep a general idea of where you are. The missions are not long, about two hours. The maps you get have enough detail so that you can read the contours of the hills. You try to go over this thing before you take-off. The co-pilot will do the to-the-yard kind of pinpointing, so you just need a general idea.

GPS systems will be very nice if they get all the satellites up there. This will be particularly vital to the platform. You could use the signal to keep the ship in the same place so the pilot could let it go and expect it to be in the same place. Especially needed for single-pilot craft. INS not good enough. Laser ring have lower maintenance but drift just as much.

(Lloyd) How would use a radar warning receiver?

(Grady) Most of the time you would be below the sweep of the radar so it would not do you much good. If you were popping up to take a look around, you might pick up a sweep, which would tell you to get back down. Also, if you were guiding a missile to a target, you might pick up a sweep which would tell you to break off.

(Lloyd) Do you have any active countermeasures?

(Grady) Yes. Your two big things that you have now are the IR suppressors which channel cool air around the engine and mixes with the exhaust. The second one is the chaff dispenser. It blows chaff into the rotor wake. They normally don't carry jammers. There is also an IR jammer. A high intensity source. AH-1 has it mounted on the back above the engine.

(Lloyd) What is the doctrine for using these countermeasures?

(Grady) When you get the warning you dispense the chaff. The suppressors are on all the time. The chaff dispenser and IR jammer is manual or possibly automatic, I have not been in that area for a while.

(Lloyd) What are the maximum maneuvers you feel comfortable in making?

(Grady) When you bank 45 degrees, your rotor is about skid height. If you bank 60, you're going to have to climb and you are probably going to run out of power. A 60 degree bank means two G's. This means you must have twice as much power than you need for straight level flying. You normally don't go more than 45 degrees.

(Lloyd) What are some of the climb rates you are talking about?

(Grady) 300 to 500 feet/minute vertical climb.

----- End of tape II -----

----- Start of tape III -----

(Grady) (general comments about displays) I prefer clean, uncluttered displays like the Augusta Mongoose. Not all the confusing lights, just an integrated display that uses a computer to prioritize the warnings and confirm the sensor indications with other measurements.

Do not really prefer monacle. You have to go with a larger text size because of the vibration; your eyes cannot follow it.

(General description of HUD's and head mounted displays)

Head mounted displays have the advantage of head tracked displays. HUD's really can't do that.

Would not want a directive type of voice, i.e. don't have it tell you what to do. Have it give warning.

Automatic monitors of systems that present information in a menu would be helpful. The pilot could see whether he had enough power to hover for example.

(Merlin) Does the helicopter have an autopilot or assist?

(Grady) The older ones do not. The Cobra has a stability augmentation system. It can't be flown without hydraulics. The new ones have a "poor man's autopilot". It has an attitude hold system. The new Sikorsky job has an attitude hold that will follow a heading "bug." Unsure whether the Apache has it or not, but they have the capability. Apache has a heading, attitude reference system, HARS. 3-axis gyros and accelerometers feeds gun systems and aircraft systems.

(Ellie) What sensors would you like?

(Grady) The wire situation is the most critical. For the most part, you can deal with the branches, but you just can't see the wires.

(George) Do you have any kind of clues as to when there might be wires around?

(Grady) You learn to be very cautious when going between hills. You learn to look for the poles, which is fine if your not in a combat situation. When someone is stringing wire, you are cautious about ridgelines and going through the passes. Normally they will be low to the ground except in the middle of the pass which is their high point.

(George) What do you do if there are wires around?

(Grady) You slow way down and fly to the side of the pass where the wires will be lower. If I go through the middle, I get right on the deck. Yeah, if there are wires around, I'd slow down.

Wires are mapped on your hazard map, such as power and telephone. The commo wire is probably a risk you have to accept. Wire cutters probably cut the risk in half. As long as the wire doesn't get between the rotor disk and the top cutter, you're probably safe.

(Merlin) If you suddenly came upon a clearing after flying in the trees, what would you do?

(Grady) I would stop and look first. Then I would probably stick to the treeline. If I knew I was in a safe area, I might try dashing across as I could do it. If I suspected any threat at all, I would stay next to the trees. Any opening is a worry. Every ridge-line you go over is a sneak up and look operation, you don't go blasting over.

(Merlin) Go over again the differences between a scouting, attack, and rescue missions as far as planning.

(Grady) They would fly about the same as far as keeping down in the trees. The scouting mission will be more random as far as routing. He will go to a general area and move around there. The attack will not do much scouting, and will have a better defined mission. Same with the rescue or med-evac missions.

(Grady) (general response to questions about navigation) Inertial platforms drift too much when you are talking about a few meters. You mostly rely on maps to show you terrain. The maps can't show the threats because it takes too long to get a new photo taken and given over to the pilot.

(Merlin) What about weather?

(Grady) LHX is supposed to operate in all weather. It really restricts your vision, make navigation more difficult. Possibly operate with a half-mile visibility, but not the pea-soup fog we sometimes get. Nothing available.

(Merlin) If you come around a corner and there is fog down in a valley or pass, what would you do?

(Grady) Try to change course. The enemy down in the fog can usually look up through the fog and see you. Also, sound travels much better so he knows your coming.

(Grady) As I see it, your computer works like a fault tree. At each decision point you go through a thought process. Any time you round an obstruction, or you change your threat environment, or you can see them, you go through a thought process. Foremost is threat. This determines how much exposure you can tolerate. From the amount of exposure you can tolerate you can then satisfy your airspeed, because the faster you go the sooner or later you are going to pop around a corner or reach a point where you are going to have to unmask to slow down to keep you from hurting yourself. So that is also going to determine your altitude, which again, is coupled to the masking. If I was unsure what was in the pass or on the other side, I would certainly not go in very fast which would cause me to flare and unmask. I would start slowing down about here (pointing to a point about half way back along the ridgeline).

----- End of tape III -----

----- Start of tape IV -----

(George) What are some of the things that tell you the threat situation is not what you thought it was?

(Grady) Probably the only source is the guys on the ground if you're going to support a ground unit. They will communicate with you and tell you if they have seen a ZSU-23-4, or if the tanks have moved. A lot of the troops are on scouting missions. You are very dependent on that. As far as getting the front-line commanders information back to the base where you have preflighted, that may never happen.

You can see tracer bullets which will tell you something is shooting at you.

(George) What do you do when something starts shooting?

(Grady) Put something between me and him as quick as I can and damn everything else, because I know something deadly is out there. Put a tree or hill between us. That will even work with a heat seeker if you see it fire. You will also punch the chaff as well.

(George) Aircraft threats.

(Grady) Helicopters are an important threat. Detection will have to be visual since radar at that altitude will have a lot of ground clutter.

(general discussion of map displays)

(general discussion of pilot duties)

(general discussion of warning systems)

(Grady) If I got a warning for wire and didn't see a wire, I'd go for altitude. If a guy is over 40 knots, you're greatly increasing your chances of hitting a wire.

(Ellie) Do you ever touch down?

(Grady) No, you never touch down. It is just too unsafe. If you run into a dangerous situation, you might back up to a clearing and hover while choosing a different path.

This should be done before you start out. The area is usually small enough for you to go over all the paths you might take.

(Grady) You can sometimes let go of the collective, but you usually have to keep a light hold of the cyclic because any gust of wind will tilt that vector.

APPENDIX B

May 5, 1987

This is a partial transcript of four tapes recorded during our interview with four helicopter pilots at the Marine Corps Air Station, Tustin (MCAS, Tustin). Attending the interview for Odetics were: Lloyd Tripp, George Westrom, Ellie Kurrasch, and Merlin Hoyt. The MCAS pilots were: Capt. Mark Boyce, Capt. Dave Kitsch, Capt. Brian Delahaut, and Capt. Chuck O'Neal. The speakers will be identified by name if possible. If a particular pilot cannot be recognized, the generic name Pilot will be used.

TAPE 1

(Overview of the Threat Expert System by Ellie, George, Merlin, and Lloyd)

(Brian) (Speaking about the Threat Expert System overview slide described by Merlin) How come you have the communication link going to and from the Threat Expert System Advisor however it doesn't go from there to the Known Threat Types and Locations? I mean you are going to continue to update on something like that. Wouldn't you want that real-time update?

(Merlin) Yes, we really will. I really should have a two-way arrow into the known threat types.

(Lloyd) (Interjecting) That was really intended to be a preflight dump.

(Mark) What you are saying, is that through your system you will be able to identify threat locations that you may have not been able to identify at your S2 brief before you took off, and maybe there should be an input between these two also so that there will be real-time feedback on your threat situation.

(Merlin) Yes, really should keep it up to date.

(Brian) Are you familiar with McDonnell Douglas and the CAPS and CAMPS systems? They have all this information in them. They have the known threat types and locations, and terrain data. It is all three dimensional. You plan your routes and it gives you your fuel, mission planning, it tells you where your (unknown utterance) systems are.

(Dave) It will give you ECM coverage.

(Ellie) Preflight planning?

(Pilot) Yes. Preflight planning.

(Merlin) I have seen a briefing on it.

(Ellie) I have a report on it that somebody sent me, but I have not looked at it yet.

(Dave) (Clarifying) The old one is CAMPS. The new one is TAMPS.

(Brian) Fantastic system.

(Merlin) McDonnell Douglas? That's not the one I've heard about.

(Ellie) Was that done for the Marines?

(Dave) I'm not sure who owns it. The Marine Air Tactics Squadron 1 gets it for all

the Nuclear Weapons and Tactics classes down there. They give a cursory class on how to use it down there. It's primarily designed for fixed-wing flight. It works better in their regime, their air speeds, their routes.

(Brian) They had it adjusted for helo's in the last class.

(Ellie) Is this a simulation?

(Brian) No. They take all the S2 briefs and put it on a data disk that can be updated within 24 hours.

(Dave) It is a 5 piece modular system culminating in a 3-D CRT printout of the area and you can type in your route and it gives you an overview display. You get all the information you want on your route and it will print your route showing all the threats and it will give you a side view showing the angles of coverage so you can see what altitude you have got to be at to avoid detection.

(Brian) It is very user friendly because it uses a mouse. You put your map on a display board. Once you have located the lat(itude) and long(itude), the computer knows exactly where you're at, and then rather than having to punch in a particular check point on you're route, you just take you're mouse and put it over the check point punch this little button. The system automatically reads that lat, long and the computer will tell you if that is a feasible routing at that altitude to avoid the threat. This is all pre-flight planning.

(Ellie) Do you know what computer that was?

(Dave) I can give you the number of the people who do.

(Lloyd) I want to get a better idea of your experience level so that I can coach my questions about the scenario, and better interpret your answers. All of you guys are helicopter pilots?

(Pilot) Yes.

(Dave) For years of experience, most of use have a common base of experience. We start off flying turboprops for about 115 hours, roughly 6 to 8 months. Then we start flying jet rangers, a very simple helicopter, and either go to a more advanced jet ranger, the guys are now, or those of us who went before, to Hueys. There you get your cursory look at tactical flying, low level routes. After that, you come out to your placement air group here. 46's and 53's are what we fly here. They are assault support helicopter, cargo and troop lift.

(Mark) The CH46 is a dual rotor aircraft, and the CH53 is a main rotor, one large rotor, one tail rotor.

(Dave) We fly about 45 hours or so. From there you go to your tactical squadron, one of the six other squadrons on the base. You progress along your syllabus and get designated as an aircraft commander. You pick up more and more tactical ops, section leader, mission commander.

(Mark) The syllabus is defined by the TR manual. It lists all the different missions and profiles you have to fly. After various tests and check flights, you become designated as a helicopter commander.

(Dave) In my case, I have been flying since 1981.

(Lloyd) Have you been flying both the CH46 and CH53?

(Dave) No. Once you split up you usually don't cross. I came through flying 301's and 53's and have been flying 53's ever since.

(Mark) To define a person's experience, it is not only years, but also flight hours.

(Dave) I've been here at MAG-16 four and a half years. I'm at 1600 hours which is about average for a Captian, I guess. It is up there for a 53 pilot. Most of it is 53 time. Some with 4000 hours get most of it flying turboprops in flight school. Mike Nickelson could not make it today, but he has 3200 hours in the 53 alone, he has been around 12 years. The average experience for a 53 pilot at Tustin is 4 to 8 years max.

(Mark and Dave) (Experience level of Captains and others)

(Dave) Types of missions flown? For the most part we do supply and assault support. Tactical troop inserts under night vision goggles or daylight utilizing terrain following techniques. In my position as a Squadron Tactics Instructor, 65% of my time is spent in the low-level regime.

(Lloyd) Your low-level, you're defining as..

(Dave) Low-level for us is anytime you're below 200 feet. We don't do Nap-of-the-Earth (air speed below 40 knots, and altitude below 50 feet). We are limited to 50 feet in the transport community here at Tustin. So we are usually from 50 to 150, generally down at 50. If you get a co-pilot or aircraft man who is not current, you start off at 150 then go down to 50. Airspeeds vary from the slowest of about 40 to a cruise speed of 130 for us. I did get about 50 or 60 hours flying armor attack and reconnaissance acting like a Soviet Hind helicopter.

The people down at Camp Pendelton tend to be closer to the forward line of troops than us. They send the Cobras out to check if the area is too hot for the big transports. The Marines have so few Cobras that they use them more like armed escorts and close in fire support. The Army uses the probe and scout method. They will take a little OH6 and send it forward because it is hard to see. Then they will send in their Cobras and transports afterwards. Our Cobras are too valuable to throw out in harm's way. The H57 jet ranger, which everyone here has flown, for roughly 60 to 70 hours. Then I flew a UH1 for 40 hours. Mark probably flew a UH1.

(Mark) Yes.

(Dave) Brian did you fly UH1's or just 57's?

(Brian) Just 57's.

(Dave) So Brian just flew 57's through flight school. Then I came out here and hit the CH53A's over at HMP301. I've been with them and the D model ever since. We don't cross ticket the E model since it is an entirely different aircraft.

Low-level or Nap-of-the-Earth experience? During the past two years, a majority of my time has been spent doing low-level stuff. Night-vision goggles, air-to-air combat, or terrain flight. I do the instrument work to stay proficient and the other (hups?) to keep my currency up or to check other pilots out. NOE for us here is nil.

Night or adverse weather? I have 125 hours on night vision goggles.

(Lloyd) Is that enough to become what you consider proficient?

(Dave) It is in the Marine Corps. The Army wouldn't think that was anything. The warrant officers all carry about 400 hours normally. You are allowed to become a night vision instructor after you have had 25 hours.

These are the binocular kind. They limit your field of view to about 40 degrees. They mount on your helmet so you still have peripheral vision to see your instruments, but can still see out through your goggles for the distant viewing. Visual acuity is, at best, something like 20/200. So airspeed and altitude are limited. You fly at about 100 feet on night vision goggles. I would not fly without them at night because you can still see things. Most of my experience with them is as an instructor.

Adverse weather experience? Only when I have to. For the most part we don't have much of that. We really don't practice that. Due to terrain limitations, we don't intentionally go out in bad weather. We usually just land and wait it out, we don't practice too much of pressing on.

(Brian) I have been flying since 1982. I've flown the same type of missions as Dave over here. My experience is mostly on the boat. A lot of boat operations and assault support and mission planning.

Types of helicopters I've flown? Again, CH57 jet ranger. I've got about 100 hours in that. Then the CH46. My current flight hours are about 1350. Most of this time has been flying at 200 feet or below. WTI (Weapon Tactics Instructor) in the squadron. Our purpose is to train the junior pilots on tactics. I have about 60 hours in the night vision goggles right now.

A lot of the boat operations are dawn assaults. One particular one was flown with no communication, and no navigational aids, so you were flying by dead reckoning. If we had something like Omega-nav, we could have been positioned farther from the ship.

(Lloyd) Omega-nav is a radio or inertial navigation system?

(Dave) Omega-nav is a radio nav system that uses radio transmission stations and a receiver on board the aircraft. Omega-nav is the Litton 211 system. It has the buttons for GPS, but not all the satellites are up yet.

(Brian) One of the things that might help you is the type of missions that each of the services performs. The Army does extensive armor attacks and scouting, the Air Force does the rescue, and the Marine Corps big thing is assault support.

--- End of tape 1 -----

(Middle of conversation) (Mark) ... We can get you the addresses for getting copies of your own.

(Dave) Each of the services has what is called an ASH manual or a task manual. This one here is for an AH-1. There is a lot of general stuff on threats - what they look like - and specific information for Cobras on mission flight. For the 53's, we're pretty much required to know what's in here.

(Lloyd) So the Army has something similar to this, you think?

(Dave) Yes, they do.

Here's the ones for the 53's and 46's.

(Mark) Now a lot of the information in each of the manuals will be the same. For example, the tactics, the discussion of the enemy threat. The sections that differ are on the specific aircraft mission, weapons capability and things like that. So while they are massively large, a lot of the information is the same.

(Dave) They contain generic information on nuclear, biological, and chemical precautions, threat recognition, terms, general shipboard operations. They contain specific stuff on, in our case, assault support, combat resupply, recon insert or extract, or troop assault. With the AH-1's they would have armor attack, or air to air.

(Ellie) So if I write to them...

(Dave) I would think so. They are not classified. They are for official use only. I don't think there has been any problem of civilian firms having them before.

(Mark) Here you go, first page. Other requests can be referred to:

Commanding Officer
Naval Air Technical Services Facility
700 Robbins Ave.
Philadelphia, PA

(Brian) I think something, too, that you might want to consider when designing your system, is that the printout you have, if it corresponds to what is in the manual, it will be more user friendly. That way we won't have to transcribe it. Especially on night-vision goggles when you are planning your mission and getting your route cards out to the pilots. The TAMPS system was not user friendly. It printed out all the information you needed, but it had to be put on another sheet of paper to use on the flight. The computer printout was this long (open arm gesture), so instead of having route cards that were this big (8.5"x11" ?) that could be read easily you have this big printout.

(Mark) He's talking about a human factors problem.

(Mark also relates a problem about reading maps while flying)

(Brian) If you make it 3-dimensional for the pilot, he can go through the terrain on the computer. One, that facilitates a map study. Gets it in his mind so he doesn't have to look at his maps and route cards to determine if the terrain he sees corresponds to the route he is flying. I know that the system down there (TAMPS) did not have that and it would have been a lot easier (if they did). Just looking at contour lines does not always tell you what the terrain is like.

(Discussion of assault support mission)

(Ellie) Is this a typical map you have to work with? (Pointing to a map in the ASH manual.)

(Dave) It is Xeroxed right off the ... That's east Yuma right there.

(Mark) It is. One of the thousands.

(Discussion of maps on the wall of Twenty-nine Palms area, and how the maps have to be folded to be usable in the cockpit.)

(Discussion of one vs. two pilot helicopters)

(Dave) We are doing something now called the ACM box. Helicopter air to air or helicopter vs. fixed wing. Where we used to do it in the middle of a flat terrain so we would not get broken, and the jets would come at you and we would go at it. Now, we are going into the terrain at 50 feet at 50 knots and we look for them and they look for us. When we find them, we have to get to altitude and air speed. Down there in some of the mountainous areas, it is really a high work load evolution. You are trying to fly and avoid the rocks, and keep him from using his weapons and trying to get a shot on him. It is one of the higher work load things we do. I know from being an air-to-air instructor, that if you get a guy over there — and its the first time he's seen it — that he is non-functional in the airplane, so you are essentially single pilot. From being in that situation, I would not want to put anybody in that situation. I find it hard enough for my self.

(Merlin) Is this primarily attack avoidance or defensive capability?

(Dave) Yes. Right now, given the transports, we are not armed with anything but defensive 50 caliber. Air-to-air is a general term everybody uses, for helicopters it is technically called EVM, evasive maneuvers. All we are trying to do is stay alive for two minutes while we call our escorts in to pick the guys off our back. If they are pressing the attack, and we can get a shot off, we will. The Cobras in the Marines are now armed with AIM-9 Sidewinders so they have a way to shoot back. So we do practice it with helicopter vs. helicopter, and helicopter vs. fixed-wing scenarios.

(Brian) The Marines are looking at ESM that can automatically respond to the threat without the pilot's intervention.

(Dave) In the ASH manual, it talks about the kind of gear we have on board, our radar detectors. It talks about the updates. The update he is talking about, the ANAPR-39 Alpha, it detects the electromagnetic radiation, classifies them as hostile, unknown, or friendly, and then will give you a synthesized voice readout. Like he said, they are working on it so it will respond without any interaction from the pilot. As it stands right now, all we get is a strobe, and we have to identify it ourselves. This one is attempting to identify it for you so you can trigger the stuff. What he is talking about, is the next generation where they are trying to get it to identify and react before the pilot gets a chance. With a heat seeking missile launched from 2 miles, you have about 3 tenths of a second to get your chaff or wires out before you're a "smoking hole." For us, by the time you register it and figure out what it is, it is often too late.

We need equipment that is designed for helicopters. Because of our work loading, we cannot "come inside" and do a lot of the "switchology." Nothing we have in the helicopter is hands on throttle and stick. Everything we do, you have to reach for, bend over, look inside for. That's when the problem occurs for us, because once you do, you loose your guidance outside or your acquisition on a target.

(Mark) That's why you need two pilots.

(More discussion about two pilot vs. one pilot concept)

(Dave) Our problems really stem from the crew coordination. We have had more accidents from crew coordination — passing back and forth — on account of a threat, terrain, or bad weather. That's where a lot of our accidents come from — who is on first. There is no real delineation of duties even though you brief it every time.

(Ellie) Is there any documented — about the number of accidents — based on that sort of thing?

(Dave) The Naval Safety Center in Norfolk, VA. has... I mean we get printouts all the time. You would have to get it released from them since it is for official use only. They give you statistics on crew coordination mishaps. It is amazing the amount of time it will happen — vertigo or something. Down at low level, where the work load skyrockets. Where all of a sudden you have one guy whose dedicated duty is navigation or sensor operation and the other guy's is just to fly instead of swapping back and forth.

(Lloyd) You mentioned all these countermeasures. Does the 53 have chaff and flares?

(Dave) Yes we do, but it is right out of the back of an F-4. They put it in a pod and mounted it on a 53. It has chaff, flares and jammers on it, but, of course, the jammers weigh 4 pounds and drop in 2 tenths of a second from a 53 because we are not at 50,000 feet.

(Chuck) There is no intent to use jammers from a helicopter.

(Dave) No there is not, but the programmer still has jammer indications on it because we bastardized the system to get it to work for us. It was really set up for a high-speed moving jet — the intervals on the chaff dispensation.

(Mark) We have a threat indicator in the cockpit that tells you what direction the threat may be coming from, a radar signal for example, but it is still left up to the pilot to determine what the threat is and to decide to use flares or chaff. The problem is that nobody knows how to use it.

(Dave) It's all done by audio signals, and there are not that many people who (know what they are).

(Mark) We don't have a place where we can go to practice actually using that so a lot of people don't know how to use the system.

(Brian) I've got a good tape of it, the Ford Aerospace has got this thing called the (TRGT ?). It's a Russian radar that we use on the ranges to illuminate you. We never got a lock on within 1 k(ilometer). So, by the time we got the tone, we were on top of the target and didn't have any time to respond to it. I can show that tape because it really opens your eyes. The only way I was able to break lock on it, was to dump all my chaff and flares. Leave a cloud the size of a 46 behind you basically. Firing 1 or 2 didn't work. On autotrack, he had us the whole time.

(Dave) The guy comes up electro-optical until you get in range, then he comes up autotrack, and by then it's a conical beam and it is too late to get away. He doesn't come up in search mode because he knows you can pick him up.

(Mark) The threat out there is pretty nasty. When I was Gallant Eagle last summer, they had the New Mexico National Guard with the Roland. They had the guy in the back with the radar doing the search, and as soon as he picks up the target, he slews the guy in the middle with the missiles to optically pick up the target. I'll tell you what, with the Roland, there is nothing you can't track, because the joystick and the speed at which you can slew the turret is so great.

(Dave) The problem is that the ATR we have right now — the radar warning we have now — is a tremendously high work load device itself. You have to scan way down (in the cockpit). It's down at the bottom there. It's a little CRT readout with a strobe

which generally gives you heading and guess distance off it — it is not accurate for distance — and you have to recognize just from the tone and the squelch what the threat is. Not a real good system. That's it for our ESM capability. That and a UHF ADF (Ultrahigh Frequency Automatic Direction Finder ?)

(Lloyd) (I ask Chuck to talk about his piloting experience.)

(Chuck) About 6.5 to 7 years of experience. 1700 hours of flight time. Primarily CH46. Mostly assault support missions from land as well as from ship. Marine Corps don't fly NOE for transport, so mostly low-level and contour flying — about 500 to 600 hours in the low-level environment.

(Lloyd) The night vision and the instruments, do you still fly at low level?

(Dave) The darker it is, the lower you get. You've got to be able to see the ground. We don't fly any lower than we do during the day, for certain. Like I said, we are usually up around a hundred feet, fifty feet if you know the area well and you know the obstacle heights.

(Chuck) The idea behind the night vision goggles is to be able to fly tactically at low levels in hours of darkness. If you've got the goggles on and you're up at 500 feet, you've defeated the purpose of them.

(Merlin) It sounds like you have a strong emphasis on night operations.

(Dave) We would like to. Unfortunately the goggle availability, the night training availability, we have strict requirements on moon angle and moon illumination. The AN-PBS5 night-vision goggles require about 10% illumination — 20% if you don't have much experience — to use them effectively. You have to wait until the moon is at certain angles, because it will cast shadows. Due to the lack of training areas in Southern California, we have to fly to Yuma, Arizona or Twenty-nine Palms to utilize them.

(Ellie) The shadows really affect your vision a lot?

(Dave) Yes, it is just like during the day on goggles. It masks a lot of things too, obstacles, threats, navigational aids.

(Mark) Let me cover my background. I have 7 years experience in flying, and 1000 hours. I'm here as a "typical" pilot. All the other three have been to WTI (Weapons Training Instructor School) in Yuma. That's between 1% and 3% of Marine Corps helicopter pilots. I have flown tactical troop inserts and tactical resupply both from ship and on shore. CH53A and CH53D helicopters.

(Lloyd) How long are some of your missions, in hours?

(Mark) The average mission is 4 to 5 hours based on FRAGs, going out and supporting somebody. That includes some "hot" refueling.

(Dave) We are more efficient when we piggy back missions like that.

(Ellie) How long does it take to refuel?

(Mark) About 15 minutes at most.

(Chuck) The missions are usually back and forth.

(Lloyd) Does that mean your radius of operation is 200 km.?

(Dave) That's a long one. A 100 mile radius is about as far as you want to range if you don't have some kind of auxiliary fuel. That would be a good mission. That would give you essentially no time on station. You go about 230 to 260 max on a bag of gas.

(Mark) Our mission does not require us to go out very far.

(Merlin) What would be your typical legs?

(Dave) 50 or 60 miles.

(Brian) Another thing, too, is don't look at these missions as miles, look at them as time. A 46 can stay in the air about an hour and 30 or 40 minutes. In the low regime, you're using a lot more gas than you normally would.

(Dave) Yes, after about an hour and 45 minutes you are looking at some serious flight planning because it is only 2 hour and 15 minutes to flame out.

(Ellie) Do you fly in groups?

(Dave) The section is the basic maneuvering unit. There is not too much single airplane. That way you can support and help each other out. Larger missions require divisions of 3 or 4 aircraft. Big troop inserts require 8 plus. Down at WTI, Chuck, Brian and I have all run missions with 20 or 30 helicopters on the same mission running to the same LZ area.

(Chuck) When you do that, you are going to separate your assets by either time or space. Including in that you have escort aircraft like Cobras.

(Discussion about support aircraft)

(Discussion about Helicopter Coordinator Airborne and how it is used to relay communications from the mission helicopters and the rear command post.)

(Lloyd) (I describe the mission scenario.)

----- End of Tape 2 -----

(Dave) I would go over the tree tops rather than going down a river bed. To remain unpredictable, I don't want to channelize. We avoid roads and riverbeds. We also avoid cities because it is a great place to hide. We also avoid places that look like a good place to set up a AAA site. If it looks like a good place for an ambush, we will highlight those areas and purposely go around them even at the expense, sometimes, of coming up to a 100 feet from 50 feet or popping over a little ridgeline perpendicular as opposed to going down the valley. We try to avoid being channelized, especially if there is more than one aircraft. It is not so much your problem as the guy's behind you.

(Lloyd) Do you fly in line?

(Dave) You try to break it out. If you were channelizing us here, you've got to assume

that it is only wide enough for 2 or 3 helicopters and 4 to 6 are behind you. On open plain like in a desert, we will get almost line abreast to try to get across it as fast as we can. There is a trade-off here between staying lower and masked and staying up a little higher and getting across the terrain faster.

(Lloyd) If you are flying next to a ridge, how fast would you be flying.

(Mark) In the tactical situation, flying about 50 feet, what speed would you fly at?

(Chuck) I'd keep it between 90 and 110 knots.

(Mark) You say that draw is big enough to move 3 aircraft through? Yes, that's right. Keep your speed up to get past the enemy before he can get a shot off.

(Lloyd) With the CH53's?

(Dave) They have bigger rotors and can stop faster, but , yea, I can see my self going through there at 100 knots. Because, again, you start killing your time on station if you start going 40 knots.

(Lloyd) You don't want to get anywhere near this ridge, here.

(Chuck) No. Actually, depending on how sheer the face is, you probably want to be to the shadow side to mask you from overhead.

(Mark) And to mask your shadow, too.

(Chuck) There is less chance of an overhead aircraft from picking up your glint or shadow.

(Ellie) The time of day is very critical.

(Dave) Yes, for both sides. For their acquisition, and for navigation.

(Lloyd) When you get to this saddle point, do you slow down or slip right through?

(Mark) (Describes the maneuver)

(Lloyd) So you maintain about the same airspeed?

(Mark) Yes.

(Dave) Yes. The only thing you have to worry about terrain flight altitude is dipping the rotor below where the fuselage was. What we do is pull some power to lift the fuselage up so the wing tip won't dip down below where the fuselage was. This will keep everything above the 50 foot altitude. (When we stop we rotate about the tail rotor rather than C.G.)

(Lloyd) How long does it take you to stop? I mean the time or distance.

(Dave) It depends on a number of things. The most important is the type of aircraft. These guys (meaning the pilots of the CH46) can stop on a dime.

(Chuck) Well, the 46 with its tandem rotor can be stopped by pulling the nose up or

we can do a side flare.

(Dave) For us (meaning the CH53 pilots) we are pulling back 20 or 30 degrees and pulling power. We are twice as heavy with not quite twice the power. So its power, weight, density of the atmosphere, time of the day. If it is the middle of the day here, you're talking a lot more room to stop because it's hot. Realistically, it is hard to estimate. It's one of those things you feel for.

To come to a complete stop from 100 knots, would take me better than 100 yards, and that is doing a *good* quick stop. That's a well coordinated effort using everything available on the airplane. With a full load of fuel on a hot day you can probably double that.

(Brian) I think I could stop in about 25 feet. (In a CH46 doing a side flare.)

(Lloyd) If you have this large clearing between this gap and the river area, something that would take 15 minutes to get across *(This is way too long. Based on any kind of reasonable scaling on the scenario, it should only be a few hundred meters to the river.)*

(Dave) You pour through. Generally, you may take a stop at the last point where you can get a look across. You may slow down or come to a stop hover forward, take a quick look, and if you see it's clear, dash across. You should take one last look before you are committed. If you see it approaching, or the navigator tells you it's on the map, you should slow down and take a look to see that it is clear before dashing across. Most helicopters accelerate fairly quickly.

(Lloyd) What, take it up to 120 knots?

(Mark) What ever we can get.

(Dave) Yea, depending on what you face on the other side. Are going to have to get rid of it (the speed) or can you hang on?

(Merlin) If you had a clear area with some trees or terrain around to the side so that you had a choice between dashing across or taking a little longer route to get some masking, do you have a feel for what you would do?

(Dave) It depends on the threat. If I was told that there was a lot of guys running around out there with SA-7's, I'd be going behind the trees. If it is basically small arms, or you need the stuff in a hurry, or it's a high priority mission, I might consider going across.

(Brian) Another thing you might want to consider is displaying the topography of the area. If you could tell us the type of terrain, if there are trees there, the shadows we would see at that time of day, it would help us plan our mission better.

(Dave) Yes, if you could tell us where the shadows are going to be, it might be worth it to stay in the shadows a little longer to stay masked.

(Discussion of risk assessment. Up to individual pilot. Each individual has a comfort level. Deciding when and where to hide is up to individual. All you can do is assume some standard level of performance and hope you get it.)

(Dave) The Army pilots are superb NOE navigators because they are looking up at the

tree tops while we are looking down at them. If you show a route like this where you are bending around (pointing to the scenario), if you get disoriented, you are not going to end up in the right area. We have to make the routes easy enough to navigate.

We have some terrain flight routes. Here are 1-in-50's (a contour map) we did in Yuma. These are terrain routes that we fly at 50 feet. It's relatively easily recognizable terrain, but it is relatively high in elevation. The route is not long, but you'd be surprised how many people get lost. It's because of the great angles of change at the navigational checkpoints. In a real route, we will straighten it out a little more to make it easier to fly. We do this if we *have to*, but we straighten it out if we can. When you have got too many corners, especially on goggles, it's really hard to look at your map underneath and try to figure out where you are going. A lot of it is more time and distance and looking for more easily recognizable check points and hope your cover will let you use a more known check point.

(Lloyd) When we get to the creekbed, which is wide enough for a single helicopter to fly down, would you guys fly beside it?

(Mark) You want to stay masked from the road, not being certain where the SA-9 threat is or the SA-7 threat is. You know that forces are generally going to move down known avenues of approach like roads. So rather than going down the river, I would cross the river and get into the next terrain.

(Lloyd) Now you are into this hilly area here, so you are exposed.

(Dave) You use the terrain. You are only 50 feet up. So I can actually go up into the hills and come around and cross the road.

(Mark) As long as the enemy position is on the other side of the hill, you are masked.

(Lloyd) When you start to approach this road and wires here, you are flying above the wires most of the time. Do you ..

(Mark) (Interjecting) Actually, you are below the wires until you pick up the poles and the wires, and then you will do your climb.

(Merlin) Would you tend to go for the poles to know that you are clear?

(Mark) Our tactics say you look for the pole and go for the pole because you can't see the wire.

(Dave) We pull both power and cyclic to keep up the same airspeed.

(Lloyd) Are the wires marked on your hazard map?

(Chuck) You want the wires marked, but even in a well known area there are omissions. You try to mark the locations and altitudes so you will know how to avoid them.

(Dave) If you have the maps, that's great. We go into an area with the idea that there are obstacles out there. This is where 2 sets of eyes helps out.

(Chuck) Wires tend to follow along roads. So this will alert you to look for wires.

----- End of Tape 3 -----

(A moving map would be nice. One that would indicate your position.)

(Lloyd) What kind of resolution are you looking for?

(Dave) Right now we have 20 meter contour interval, and I think it is inadequate. We used to have the foot map which was 40 feet or something which was ok. With 20 meters, you will miss entire peaks and rocks. As a minimum, I think you need the meter interval (meaning 20 meter contours).

(Chuck) When you are talking about a 1-in-50 (meaning a scale of 1:50,000) you are talking about a terminal area or a blowup of a known check point. For any distance, you are going to a 1-in-250 (meaning a scale of 1:250,000) anyway.

(Dave) You're right. We will use this for the entire mission and use the 1-in-50's for checkpoints or terminal phase.

(Lloyd) In this open area, instead of being just being flat, you had sparsely placed trees. Would you just fly over them in a straight line, or would you weave between the trees?

(Mark) No.

(Chuck) It is probably a waste of effort to maneuver around them.

----- End of tape 4 -----

APPENDIX C

Appendix C

The purpose of this appendix is to describe the actions and rules of the Threat Expert System in greater detail than is described in the body of the report. This appendix will also try to provide some insight into the assumptions that are inherent in the design of the Threat Expert System. In the course of this description, actual function and rule names will be indicated in **bold**, and the names of the files provided to NASA-Ames Research Center will be indicated in *italics*. Although actual code segments will not be a major part of this appendix, some code will be included to show some implementation details that may better explain the Threat Expert System. For these code segments, some basic familiarity with LISP and ART syntax and semantics will be assumed.

The Threat Expert System architecture shown in Figure 5 on page 24 provides a logical structure for examining in detail the elements of the Threat Expert System. What is not shown in Figure 5, are the underlying mechanisms in the ART expert system shell that maintain the databases and determine which rules to execute. This figure is an idealized representation of the separation between the databases and the six rule modules. In reality, ART only has two data structures that can be accessed by the users, namely the rule base and the fact base. This means that all the data in the Global Databases, Blackboard, and internal facts to the rule modules are all aggregated into the fact base along with many facts used by the ART system. Likewise, all the rules in the rule modules are really aggregated into the rule base. Because the Threat Expert System is easier to describe if the rule modules and databases are really isolated from each other, it will be assumed, for the purposes of this appendix, that they are. The file *relations.art* contains all of the fact relations that are used in the Threat Expert System. These defrelation statements provide additional detailed documentation about the facts that are present in the ART fact base.

The examination will begin with, what are called, the Global Databases and the Blackboard, and then proceed to the six rule modules.

The Global Databases and Blackboard.

Some understanding of what is represented in these databases and how it is represented will be important for understanding the rules and functions

Terrain Data. Part of the knowledge that was included in the Threat Expert System are the techniques used by the pilots we interviewed for flying very close to the ground to avoid radar detection. To illustrate these techniques, a terrain database is required. The terrain database started as a hand-drawn illustration of mission scenario that was used as a reference for discussion during the pilot interviews. While some of the information provided by the pilots was of a general nature, much of it was geared toward the illustrative mission scenario used during the interviews. It was fitting, therefore, to use the same scenario in the Threat Expert System terrain database. Rather than starting with a 3-D database of the scenario and using perspective graphics to draw the scenario on the screen, a perspective illustration similar to the one used during the interviews was drawn on the screen first and then the terrain data was added later. This method permits a more detailed graphic display at the expense of a terrain database that is not truly 3-D. While starting with a 3-D terrain database would result in a more conventional terrain representation (similar to the data that could be obtained from a contour map), the graphic display would look very rough with terrain data points spaced no closer than 10 pixels. Drawing the graphic display from a 3-D database would also require the creation of terrain data points that cover the entire scenario

as well as the development or purchase of graphics software that will draw the scenario with hidden line removal. Movement of the helicopter icon through the scenario would also have to be done in perspective with hidden line removal. Using the method that was selected, terrain data points only have to cover the primary and alternate mission routes since they are not directly linked to the graphic display. This greatly reduces the effort required to fill in the terrain data points as well as the amount of computer memory required to store the terrain database.

The graphic display was created using the icon editor tools found in the ART studio. It is essentially a collection of separate icons that are displayed in one window. The icon editor represents icons as ART schemata or frames containing information that describes the icon so other code in the ART system will know how to draw it on the screen. The collection of icons that represent the scenario display are located in *background.art* and *shading-1.art*. A more compact form of the scenario display known as an image is located in *back_image_1.art* and *back_schema_1.art*. Since the image loads much faster and consumes less space than the original schemata, it is used instead of the icons.

The terrain data points that were created for the scenario are located on a 10 pixel by 10 pixel grid located within the boundary of a polygon described by the following list of vertex locations measured in pixels from the upper left corner of the scenario window: (10,470) (340,470) (340,270) (1030,270) (1030,50) (230,50) (230,370) (190,370) (190,410) (10,410). This polygon roughly covers an 80 pixel wide path along the primary and alternate routes. The terrain data points are originally represented as icons which helps in determining the location of a terrain data point relative to the scenario graphics because it can be displayed right on top of the graphics at its designated location. The following is an example of one of the over 2300 terrain data points located in the file *terrain-schema.art*.

```
(Defschema Terrain-Point-1
  (Instance-of Text)
  (Instance-of Icon-Primitive)
  (Instance-of Graphic-Icon)
  (Instance-of Instantiated-Icon)
  (Contained-In-Icon Background)
  (Input (Terrain-Point-1))
  (Alu Xor)
  (Translate (10 410))
  (Scale)
  (Rotate)
  (Transform)
  (Origin)
  (Text-String "**")
  (Endpoint (10 0))
  (Elevation 45)
  (Terrain-Type Rocks)
  (Icon-Extent (10 400 18 412)))
```

The Terrain-Types slot can have the following values: Flat-Ground, Rocks, Water, Trees, Bridge, Road, Wire, and Pole. While Bridge, Wire, and Pole are usually associated with obstacle maps, they are combined here along with the terrain data.

While the icon representation of the terrain data points is probably the most general, one can see from this example that there is quite a bit of data associated with each terrain point as well as a number of hidden procedures. All of this adds up to a large computing overhead that causes the ART system to operate very inefficiently. One way

to get around this inefficiency is to extract the essential information about the terrain data points found in the Translate, Elevation, and Terrain-Type slots, and put it into a LISP array. The code for doing this is located in *make-terrain-array.art*. All terrain data required by the rules can then be referenced very efficiently using this LISP array.

Sensor Data. The information in this database is a collection of facts asserted by the rule radar-detection-outside-threat-area located in the file *sensor-fusion.art*. This rule and its associated supporting LISP functions located in *sensor-functions.lisp* acts like a simple radar warning receiver model. The condition for the detection of a threat is:

$$\text{threshold} \leq (\text{altitude}/40) * (100/\text{distance-to-emitter}) * \text{random}$$

Where:

threshold = 0.06

random = random number < 1.0 and \geq 0.0

This function was chosen so that the higher the helicopter is flying and the closer it is to the threat, the greater the probability will be that it is detected. The threshold was chosen empirically so that emitters greater than about 400 pixels away would not be detected. (The random number generator prevents this from being absolutely true.) A distance of 400 pixels is small enough so that both detected and undetected threats can be present on the screen at the same time yet large enough so that more than one threat can be detected at the same time. Once the emitter is detected, a fact with the following form is asserted.

(RWR-warning ?time ?threat-type ?threat-x ?threat-y)

The ART variables are filled in with the time of the detection, the threat type (either Air-Defense-Gun or Fixed-AA-Missiles), and the position of the threat. The position of the threat is used to determine which threat to flash on the screen to indicate that it has been detected, and later to compute the angle to the threat by the rule *rel-angle-to-threat*.

Mission Plan. The Mission Plan database consists of a collection of schemata found in *mission-plan.art*. The following is an example of one of the goal schema.

```
(defschema Goal-Point-1
  (Goal-Location (255 412))
  (Goal-Type Intermediate)
  (Goal-Num 1)
  (On-Path Common))
```

Goal-Type can have the values: Starting, Intermediate, or Final.

On-Path can have the values: Primary, Alternate, or Common.

The goal points are the end points of line segments that define the Primary and Alternate routes. The Primary and Alternate routes were selected based on discussions with the pilots that were interviewed, not by some automatic route planning procedure.

Intelligence Reports. The Intelligence Reports are defined interactively under the control of the rules in *intel-reports.art*, and its supporting LISP functions in *intel-functions.lisp* and *intel-zfunctions.zetalisp*. The purpose of these rules is to create schemata of the following form:

```
(Schema ?Threat-name)
  (Alu Ior)
  (Contained-in-icon Background)
```

```

(Fill Clear)
(Instance-of Closed-Spline)
(Thickness 3)
(Translate (?x ?y))
(?x-points)
(?y-points)
(Type ?threat-type)
(Known-to-intel ?known)

```

The value for the ART variable ?threat-name is created automatically by appending a number on to the base name "THREAT-". This gives each threat that is defined a unique name and describing schema. The ?x, ?y, ?threat-type, and ?known variables are assigned values by the rule get-position-and-type along with the zetalisp function position-threat. The position-threat function is the one that creates the pop-up threat selection menu. By defining a target as known, the threat information in the schema will be intelligence information that is known before the mission starts. Unknown threats will have to be detected after the mission starts using the on-board radar warning receiver. The ?x-points and ?y-points variables are assigned values by the rule define-threat-extent along with the LISP function x-y-points. This rule and function read the position of the mouse when it is clicked and incorporate the point as part of a closed threat extent boundary. The rules bitblt-ADG and bitblt-SAM use the bitblt function to display the Air-Defense-Gun and Fixed-AA-Missiles icons at the position of known threats of the declared type. The rules bitblt-inv-ADG and bitblt-inv-SAM display the inverse of the icon to designate a threat that is declared unknown at the time of its definition.

The Blackboard. Like many other data structures in the Threat Expert System, the Blackboard is represented as a schema. This type of organization permits the grouping of facts used by several modules of the Threat Expert System into one named structure. The entire Blackboard is found in *blackboard.art* and is reproduced here.

```

(defschema Blackboard
  ; "The Blackboard"
  ; The following slots are written to by the Situation Assessment expert
  (SA-max-altitude) ; Max and Min altitude above sea level
  (SA-min-altitude)
  (SA-max-angle) ; Max maneuvering angles and rates
  (SA-max-rate)
  (SA-max-velocity) ; Max velocity in knots
  (SA-max-climb) ; Max rate of climb
  (SA-goal-rectangle-width) ; Goal rectangle dimensions
  (SA-goal-rectangle-height)
  (SA-current-location) ; list Current location of heli in pixels and altitude
  (SA-current-velocity) ;list Result of arbitrating between other velocity experts
  (SA-time) ; Current simulation time in minutes
  (SA-start-mission) ; Triggers the Mission Planning expert
  (SA-next-goal) ; Holds the number of the next routing goal
  (SA-terrain-types) ; List of terrain types
  (SA-terrain-below) ; Type and elevation of terrain below location
  (SA-max-scan-dist) ; The max distance to objects of any concern

  ; The following slots are written by the Mission Routing expert.
  (MR-routing-goal) ; List of the x y pixel values

  ; The following slots are written by the Terrain Following expert.

```

(TF-flight-vector) ; A sequence of x-vel, y-vel, rate-of-climb, name

; The following slots are written by the Sensor Fusion expert.

(SF-detection-threshold) ; The Radar warning receiver threshold

; The following slots are written by the Obstacle Avoidance expert.

(OA-tree-avoidance-vector) ; A sequence of x-vel, y-vel, rate-of-climb, name

(OA-bridge-avoidance-vector) ; A sequence of x-vel, y-vel, rate-of-climb, name

(OA-wire-avoidance-vector) ; A sequence of x-vel, y-vel, rate-of-climb, name

)

The Rule Modules.

The rules in the modules can be roughly divided into two functional categories. These categories are:

- 1) rules that capture the knowledge acquired from the various sources described in the body of this report, and
- 2) rules that generate and display text and graphics on the screen.

It is important to identify these two categories so that the user can distinguish between actions of the rules in category (1) and those used for the purpose of a demonstration.

Situation Assessment. Most of the rules in *situation-assessment.art* fall into category (2). They are intended to acquaint the user with the demonstration and initialize the Blackboard for the starting state of the helicopter. The why and more-why rules respond to inquiries from the user when the WHY? "button" in the Control window is moused. These rules perform this action by examining the fact base for facts of the form

(message ?message-number ?message-string)

The ?message-numbers are chronologically numbered starting with 0. The ?message-string is the text that is printed in the Query Response window. This simple query mechanism means that any rules that need to be monitored more closely only have to assert a message fact as one of its actions.

The rules update-velocity-1 through update-velocity-4 arbitrate between the velocity vectors calculated by the other rule modules to determine which one should be used to actually update the helicopters velocity. In English, the rules state: "If only the Terrain-Following vector exists, then use it. If the Terrain-Following and Obstacle-Avoidance vectors exist, then use the Obstacle-Avoidance vector." In addition to these rules, add-normal-component adds velocity modifiers that are expressed as components that are normal to the current velocity if they exist.

The function compute-new-position in *situation-functions.lisp* is used to compute the new position of the helicopter icon. For this demonstration, an accurate and computationally expensive helicopter model was not used. Instead, the helicopter is considered to be massless and consequently can accelerate to any velocity in one update time interval of one second. This same function also updates the instruments in the Instrument window.

Terrain Following/ Terrain Avoidance. The terrain following/ terrain avoidance rules and functions are located in *terrain-following.art* and *terrain-functions.lisp*. The general purpose of these rules is to recognize terrain patterns that will trigger actions

that were described during the pilot interviews. It begins the recognition process by determining what kind of terrain the helicopter is currently over. This is done by terrain-below. Once it has done this, it calculates its position relative to large terrain features in the scenario. Originally, these large terrain features, such as ridges and river banks, were going to be recognized based strictly on the information in the Terrain Database. It became apparent that even for a synthesized terrain database, the 2-D and 3-D pattern recognition problems inherent with this method were beyond the scope of this Phase I SBIR. Instead of this method, the large terrain features were instantiated as objects described by open spline curves. The rules closest-point-to-open-spline and rel-angle-to-object result in facts that create a map of the distance and angle relative to the velocity vector to all the large terrain features in the scenario. Rules such as parallel-to-ridge and over-river examine this map to see if their conditions are satisfied. If they are, then they write a Terrain Following flight vector to the Blackboard for the Situation Assessment rules to read. Other rules such as move-to-ridge-or-bank and move-away-from-ridge-or-bank generate normal components that modify the current velocity vector. The rules terrain-toward-goal and direct-to-goal are activated if no recognizable terrain features are nearby.

Sensor Monitoring and Fusion. The rules in the file *sensor-fusion.art* create and maintain facts about the identification and direction to threats in the scenario. A confidence measure is also maintained so that the more consecutive detections by the radar warning receiver model, the higher the confidence factor. If a radar warning receiver detection is missed, the rule decrement-unsupported-record is activated to reduce the confidence factor. If an intelligence report exists for a threat, then fuse-with-intel will increase the confidence factor of a threat detection report to indicate that the expected threat was detected with the radar warning receiver.

Mission Routing. The mission routing rules found in *mission-routing.art* and the supporting functions in *mission-functions.lisp* are intended to determine when a goal has been reached, what goal to establish, and when the entire mission has been accomplished. To perform the first action, the rule goal-satisfied compares the current position of the helicopter with a 20 pixel by 20 pixel area around the current goal. If the helicopter is in this area, the goal is declared satisfied and the rules for establishing the next goal are activated. A 20 pixel by 20 pixel area is set in the Blackboard as a means to relax the restriction on achievement of a goal. If the goal was a single pixel, it would be very unlikely that the helicopter would hit the goal so it would never be satisfied. Based on a scale of five feet per pixel set in *situation-functions.lisp*, the goal area is scaled to be 100 feet by 100 feet.

What goal to establish is determined by whether the helicopter is on the Primary or Alternate route and the rules establish-goal and determine-goal. These two rules examine the list of goals in the Mission Plan database and calculate what the closest goal is that is in the direction to the final goal. It then establishes this goal as the next goal to achieve by writing it to the Blackboard.

Selection between the Primary and Alternate paths is determined by switch-to-alternate. This rule examines which goals are encompassed by threat boundaries and selects the Alternate route if any of the goals on the Primary path are blocked. If both routes are blocked, the abort-mission rule is activated.

The mission is said to be accomplished when the rule mission-accomplished determines that the helicopter icon is within the boundary of the final goal.

Obstacle Avoidance. The rules in *obstacle-avoidance.art* along with the functions in

obstacle-functions.lisp are used to locate obstacles in the path of the helicopter, and to generate velocity vectors that will avoid the obstacle. The first step in this process is to generate a local obstacle map. For the purposes of this demonstration, it is assumed that all obstacles of interest are present in the Terrain Database. The rule *get-local-points* is used to get a local 6x6 neighborhood of terrain data points from the terrain data array and instantiate them as facts so they can be operated on by the rules. (Remember that the terrain data array is a LISP array made from the terrain data point schemata. Before the ART rules can pattern match to the data in the LISP array, the data must be instantiated as ART facts.) Because the terrain points are spaced 10 pixels apart, a 6x6 neighborhood corresponds to a 60x60 pixel area or, at a scale of five feet per pixel, an area of 300x300 feet. With the terrain data points instantiated as facts, the rule *make-local-mapping* asserts facts of the following form:

```
(local-map ?angle-to-obstacle ?distance-to-obstacle ?elevation ?type)
```

The *?angle-to-obstacle* is the relative angle to the obstacle as measured from the velocity vector. The *?distance-to-obstacle* is measured in pixels. The *?elevation* of the obstacle and the *?type* of obstacle are needed by other rules to determine the best way to avoid the obstacles.

The remaining rules in *obstacle-avoidance.art* are divided into three groups corresponding to the three types of obstacles that will be detected and avoided, namely trees, bridges, and wires. Trees are avoided by first determining that the area within +15 to -15 degrees of the direct path to the next goal is blocked by trees. This is done by the rule *direct-path-blocked*. If this is true, an area within +40 to -40 degrees of the direction to the next goal is mapped by *create-local-map-list* so that the rule *find-gap* can determine if there exists a gap that the helicopter can fit through. If there is a gap, the rule *forward-tree-opening* will generate a vector that will take the helicopter towards it. If there is not a gap, the same rule will vector the helicopter over the trees. The bridge is avoided by first detecting the bridge with the rule *bridge-ahead*. This rule examines the obstacle map looking for an obstacle of type BRIDGE within +30 to -30 degrees of the direct path to the next goal. If a bridge is detected, the rule *over-the-bridge* will generate a velocity vector that will take the helicopter over the bridge. The rule *wire-in-path* examines the obstacle map for obstacles of type WIRE within +30 to -30 degrees of the direct heading to the next goal. If a wire is detected, the rule *find-closest-pole* locates the closest supporting pole that is also closer to the goal and asserts a fact with this information. This fact is read by the rule *vector-towards-pole* which generates a vector which will take the helicopter over the pole.

Threat Detection and Avoidance. The rules and supporting functions for threat detection and avoidance are located in *threat-detection.art* and *threat-functions.lisp*, respectively. For threats that are already known because of they are in the Intelligence Database, no detection is required. On the other hand, an estimate of the position of unknown threats and their threat boundaries is needed. An estimate of the position of unknown threats is performed by the rule *triangulate*. This rule looks for two different detections from the radar warning receiver that are from the same threat and are at least three time steps apart. The difference between the directions to the threat measured with the two different detections must be at least 10 degrees. Requiring a 10 degree difference will assure there is an adequate base to the triangle for a good position estimate. Once the position is estimated, the threat radius is estimated by the rule *determine-threat-radius*. This rule looks at the type of threat that is radiating and assigns fixed values that are found in the following *deffacts* statement.

```
(deffacts threat-radii
  (threat-radius Air-Defense-Gun 150)
  (threat-radius Fixed-AA-Missiles 200))
```

The values are measured in pixels and were primarily chosen so that the threat radius would easily fit in the scenario display.

The threats are avoided by the two rules skirt-known-threat-boundaries and skirt-observed-threat-boundary depending on whether the threat is part of the intelligence reports or was later observed by the on-board sensors. These two rules use a similar technique to avoid the threats. This technique is explained in detail for the rule skirt-known-threat-boundaries which is show below in its entirety.

```
(defrule skirt-known-threat-boundaries
  "Given that you know the threat boundaries, try to skirt around it."
  (declare (salience 0))
  (gen-flight-vector)
  (threat-map ?x ?y ?dx ?dy ?angle ?dist&:(< ?dist 40) ?type ?threat-name)
  (schema blackboard
    (SA-max-velocity ?max-velocity)
    (MR-routing-goal (?goal-x ?goal-y)))
  (test #L(cl-user::do-not-accel-away ?x ?y ?goal-x ?goal-y ?dx ?dy ?angle))
  =>
  (assert (skirt-known))
  (assert (normal-component =#L(seq$ (cl-user::fly-from-threat
    ?angle ?dist
    ?dx ?dy ?max-velocity))))))
```

On the IF side of the rule, the most important pattern is

```
(threat-map ?x ?y ?dx ?dy ?angle ?dist&:(< ?dist 40) ?type ?threat-name).
```

Facts that match this pattern are generated by the rule rel-angle-to-threat in the file *sensor-fusion.art*. The variables ?x, ?y, ?dx, and ?dy hold the current position and velocity of the helicopter. The variable ?angle is the relative angle to the closest point on the threat boundary as measured from the velocity vector. The ?dist variable is the distance to the closest point on the boundary with the restriction that any threat boundaries more than 40 pixels away should be ignored. This is so that the rule only considers threats in the immediate vicinity rather than on a global basis. The ?type and ?threat-name provide unique identifiers for the threat that is currently being avoided. Much of the data found on the IF side of the rule is passed to a function on the THEN side called fly-from-threat. This function actually performs the calculation of the normal components that will be added to the flight vector. The code for this function is shown below.

```
;; Computes a normal component to be added to the flight vector to
;; move away from threat boundaries.
(defun fly-from-threat (angle dist dx dy max-velocity)
  (let (alpha gamma new-dx new-dy cos-alpha sin-alpha additive-comp)
    (setq gamma (round (* (atan dy dx) (/ 180.0 pi))))
    (cond ((and (<= angle 180) (>= angle 0)) (setq alpha (- (+ angle gamma)
180)))
      ((and (< angle 0) (> angle -180)) (setq alpha (+ 180 angle gamma))))
    (setq cos-alpha (cos (* alpha (/ pi 180.0))))
    (setq sin-alpha (sin (* alpha (/ pi 180.0))))
    (setq additive-comp (* 5 (/ 40 dist) (/ 40 dist)))
    (setq new-dx '(round (* (* 0.75 (+ (abs *dx*) additive-comp)) ,cos-alpha)))
    (setq new-dy '(round (* (* 0.75 (+ (abs *dy*) additive-comp)) ,sin-alpha)))
    (list new-dx new-dy)))
```

Basically, this function first finds the normal angle and then computes a normal vector whose magnitude is the combination of an additive component that is a function of the inverse of the distance to the threat boundary squared, and a multiplicative component

that is a function of the velocity of the helicopter.

The test pattern on the IF side of the rule simply prevents the addition of any normal components to the velocity vector once the helicopter has passed the threat boundary.

Restricting the rule to operate on threats in the immediate vicinity simplifies the threat avoidance actions with the attendant loss of generality to more complex threat situations. A better threat avoidance rule base would examine the global pattern of threats and threat boundaries to find a route that best avoids the them. The pattern recognition required to solve this problem was deemed to be beyond the scope of this Phase I SBIR, and is better handled by a longer term project.

Conclusion.

Throughout this appendix, actual rule, function and file names were used to map out the location of the most important pieces of code that are used in the Threat Expert System. The other functions and rules which are not explicitly mentioned by name play an equally important part in the Threat Expert System by controlling the execution or "firing" of the rules and in performing needed calculations. With this appendix, the user should be able to more fully understand the actions of the Threat Expert System when the demonstration is being executed.



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16. Abstract <p>The purpose of the Phase I research, "Threat Expert System Technology Advisor", was to develop a prototype expert system to determine the feasibility of using expert system technology to enhance the performance and survivability of helicopter pilots in a combat threat environment while flying NOE (Nap-of-the-Earth) missions.</p> <p>The basis for the concept is the potential of using an Expert System Advisor to reduce the extreme overloading of the pilot who flies NOE missions below treetop level at approximately 40 knots while performing these functions:</p> <ul style="list-style-type: none">Monitoring all Avionic and Weapon systems.Situation awareness of all aspects of the tactical situation.Assessing the threats reliably.Making split-second flight decisionsMaking split-second weapon deployment decisions. <p>Our ultimate goal is to develop a Threat Expert System Advisor which provides threat information and advice that are better than even a highly experienced copilot.</p> <p>The results clearly show that the NOE pilot needs all the help in decision aiding and threat situation awareness that he can get. It clearly shows that heuristics are important and that an expert system for combat NOE helicopter missions can be of significant help to the pilot in complex threat situations and in making decisions.</p>					
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